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A PHYSICAL STUDY OF THE WELSBACH MANTLE.*

BY

HERBERT E. IVES,
Ph.D., Captain, S. R. C., U. S. A.
E. F. KINGSBURY,
Ph.D., Lieut., S. R. C., U. S. A.
AND
E. KARRER,
Ph.D., Sergeant, U. S. A.
Members of the Institute.

I. INTRODUCTION.

THE physical theory of the ordinary incandescent mantle, composed of thoria and ceria (Auer or Welsbach mantle), has been most fully treated by Rubens.[1] He found the high efficiency of the approximately 99 per cent. thoria, 1 per cent. ceria mixture to be due to two causes: First, to the low emissive power of the thoria, in virtue of which it attains a high temperature in the flame; second, to the introduction of a rather sharp absorption (emission) band in the visible spectrum by the small quantity of ceria (when hot). The addition of more ceria broadens the emission band, thereby contributing proportionately more infra-red energy, increasing the total radiation, and lowering the temperature, so that the radiant luminous efficiency falls off again after

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Contributed by the Research Laboratories of the Welsbach Company, Gloucester City, New Jersey.

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passing through an optimum. For the details of this theory, and of the general theory of temperature radiation, on which it is based, reference should be made to Rubens's [1] original paper, and to modern text-books on heat radiation.[2]

The object of the present study was to fill out some details of the theory of the ordinary mantle, and to apply the methods of study used by Rubens, as well as certain other new methods, to

I

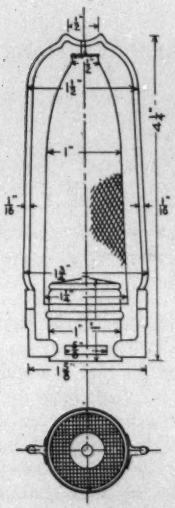
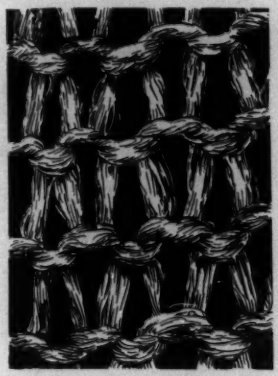


FIG. 1.

II



I. Dimension drawing of mantle and burner.
II. Photomicrograph of (silk) mantle structure.

mantles composed of other oxides and oxide mixtures. The broad aim was to improve our knowledge of the behavior of the incandescent gas mantle, in the hope that information of value in its manufacture and development would be obtained.

II. SOURCE AND CHARACTER OF THE MANTLES STUDIED.

The mantles for the work with gas heating were uniformly of the upright type, of the dimensions and shape shown in Fig. 1 (I). They were made under direction of Mr. S. Gulbrandsen by

Mr. J. G. Buckley, of the Welsbach Company, of cotton or silk fibre, as noted, and burnt off in a hardening flame, according to the regular factory procedure. The weave was uniformly of the chain-stitch variety, shown in the photomicrographs of the silk.

The weight of oxide (ash) per unit area, the relative percentages, by weight, of oxides in mixtures, the character of the weave, are all factors which have influence on the light given by the mantle. For a complete study, the best weight and character of weave, having regard to physical strength and deterioration during burning, should be determined by experiment for each oxide or mixture. In a survey of a large number of materials, such as that made here, a detailed study of each mantle could not be undertaken. Each was therefore made up of a weight and structure found practicable by rough experiment, and careful record was kept of these details. Separate experiments on the effect of varying the weight of ash per unit area made on a representative mantle and recorded below showed the limits of possible change of characteristics due to this factor. In general, any changes by weight within probable or practical limits would have been of comparatively small significance compared with the differences due to different composition.

Special mantles were made up in flat disk form for experiments in heating by the cathode discharge in a vacuum tube, and special small mantles for heating with the hydrogen-chlorine flame. These are described in connection with the experiments made with them.

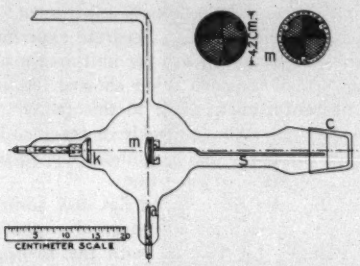
III. METHOD OF HEATING.

For the majority of the tests the mantles were heated in the usual manner by contact with the non-luminous Bunsen flame. The gas used was a representative (Philadelphia Gas Works) mixed coal and water gas, of approximate proportions 20 per cent. coal and 80 per cent. water, and average heating value of 660 B.t.u. per cubic foot, supplied at a uniform pressure of 3 inches. Throughout the work all measurements were made on the mantles without the usual glass chimney, which, although increasing the mantle efficiency, would have interfered with some of the more important tests. The question of burner adjustment proved to be one of great importance. Ordinarily the mixture of gas and air was chosen which would give the maximum

luminosity. It was found, however, that with some mantles a very marked difference of behavior appeared, depending on whether the mantle was entirely outside or entirely inside the flame. For instance, with ceria two extreme adjustments are possible—one of maximum luminosity and temperature, in the outside, oxidizing flame, the other of minimum luminosity and temperature but of maximum total radiation. As a consequence of these observations measurements were made on some mantles with several adjustments.

A further development of this line of study consisted in heating pieces of mantle in the space between the outer and inner

FIG. 2.



Special vacuum tube for heating mantle materials by cathode ray bombardment: *m*. Disk mantle. *c*. Removable ground cap. *k*. Cathode. *a*. Anode. *s*. Glass rod frame for holding mantle.

cone of the burner, or on the inside of a Meker burner flame, and withdrawing the material through a side tube. The results of this procedure will be treated under the descriptions of the various mantles.

In one case (thoria-ceria) heating of small mantles with a hydrogen flame burning in chlorine was tried, the hydrogen flame being ignited in air under a bell jar, and the air then being displaced by chlorine.

Experiments were made on some mantles and mantle mixtures by heating by cathode rays in a vacuum tube. The tube used is shown, drawn to scale, in Fig. 2. Its special feature is the removable ground cap (*c*) whose use permits the removal of the special disk mantle (*m*) and the introduction of another. The

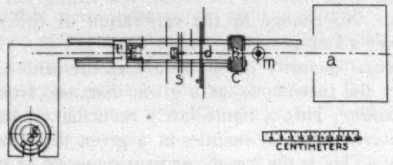
tube must, of course, be re-exhausted for each mantle, which was done by a Gaede mercury pump. The high voltage necessary for the discharge was supplied either by a large induction coil or by a 20,000-volt transformer operated on a 220-volt, 60-cycle power circuit.

IV. METHODS OF STUDYING RADIATING CHARACTERISTICS.

1. Measurement of Total Radiation.

In order to determine the efficiency of any radiator as a transformer of the energy applied to it into radiant energy, and to determine its emissive power or radiating capacity as com-

FIG. 3.



Plan of apparatus for measuring radiance and radiant luminous efficiency of mantles: *a*. Black background. *b*. Bright tin sheet with 1 cm. diameter aperture. *c*. Metal block support for tin sheet *b*. *d*. Double-walled tin shutter. *f*. Spectral luminosity curve filter. *s*. Sector disk. *t*. Thermopile. *g*. Galvanometer.

pared to a full radiator (black body), it is necessary to measure the radiant energy.

This was done on the mantles by means of a surface thermopile of 72 Bi-Ag elements (Coblentz design), in conjunction with a sensitive d'Arsonval galvanometer (Leeds & Northrup construction, sensibility 33 mm. per microvolt at terminals, resistance 12.5 ohms, period 7 seconds). The thermopile-galvanometer system was calibrated by means of a standard of radiant intensity, in the form of an incandescent electric lamp, obtained from the Bureau of Standards. The primary object of the study being the mantle itself, rather than the burner, mantle supports, etc., the radiation was measured from a definite area of the mantle, about one-third up from the bottom, as limited by a circular aperture of one centimetre diameter. A diagram of the apparatus is shown in Fig. 3. Special features are the background (*a*), consisting of a deep black enclosure or hole,

and the screen of bright tin (*b*), in which is cut the 1 cm. diameter circular aperture, supported by the large block of metal (*c*), which serves by its large heat capacity to prevent the screen about the aperture from being heated up by proximity to the mantle (*m*). A double-walled sheet tin shutter (*d*) and a very complete system of screens (not all shown in the diagram) are additional special features. The whole apparatus is set up in a thick-walled basement room, where the temperature holds fairly constant.

A complete measurement of the radiant energy falling upon the thermopile involves in general an observation of the galvanometer deflection due to the background, and of the deflection due to the metal aperture and block (*c*). The latter, because of the large mass of the metal, was negligible, the former usually so. No change in the calibration of the system was detected over a long period.

The actual quantity given by a measurement is the watts received by the thermopile, at a given distance, from a certain area of mantle. This is immediately reducible to watts emitted per square centimetre of mantle, in a given direction, per unit solid angle. This is the specific radiant intensity or *radiance*,[3] a quantity of exactly the same significance in radiation as is brightness in illumination. Its integral throughout the whole sphere and over the whole radiating surface give the total radiant emission. Inasmuch as the measurements here made are in one direction only, and from only one part of the mantle, the total radiant emission is not directly derivable from these measurements. The emissive power, or ratio of the radiant emission to that of a black body, at the same temperature, is directly obtained by comparing the quantity measured (radiance) with the similar quantity for the black body, which can be calculated from the black body laws by means of the experimentally established constants.

2. Measurement of the Radiant Luminous Efficiency.

The radiant luminous efficiency,[4] or luminous efficiency of the radiated energy, is defined as the ratio of the radiant energy, transmitted through a filter whose transmission at each wavelength is proportional to the luminosity of the equal-energy spectrum (maximum of luminosity being called unity) to the total

radiant energy. It informs us upon the characteristics of the mantle (and flame) as a light-source, irrespective of the losses due to the method of heating; *i.e.*, conduction and convection of energy away by the mantle supports, products of combustion, and surrounding atmosphere.

The instrument for its measurement is the radiometer described in the previous section, to which is added a spectral luminosity curve filter (f), composed of a solution of certain inorganic salts in water, which had been previously worked out, whose transmission through the spectrum accurately copies the luminosity curve of the spectrum for the normal eye. Measurements of the radiation passing through this screen are directly proportional to the luminous intensity of the radiation.

The complete determination of radiant luminous efficiency consists of two measurements: one, that of the radiant energy, without the interposition of the special filter (in practice cut down to measurable value by the sector disks); the other, that of the radiant energy transmitted by the screen (making proper correction for the maximum transmission, which should be 100 per cent., but is always less in any actual practical filter—in this case 57 per cent.). The ratio of the latter to the former is the desired efficiency. Details of the apparatus and its use have been given in a previous publication.[5]

Measurements of this factor were made upon the *whole* mantle, as exposed by an aperture obstructing merely the burner and burner supports. This inclusion of the whole mantle was made practically imperative because of the small amount of energy received through the luminosity curve filter when the mantle area was restricted to the small spot of maximum luminosity on which most of the other measurements were made. Because of the falling off in temperature toward the top of the upright mantle the efficiency measured for the whole mantle is considerably less than it would be if the mantle were uniform. The comparison frequently made below, between the efficiency of the mantle and that of a black body at the same temperature, is for this reason subject to considerable qualification. It is introduced largely to bring out the selective characteristic of the mantle radiation, which is, for the reason given, even greater than the data indicate as exhibited.

3. Measurement of Total Luminous Efficiency and Radiational Efficiency.

The total luminous efficiency is the ratio of the luminous energy yielded (energy passed through a luminosity curve filter) to the total energy supplied to the light-source. The luminous energy is measured in the manner described in the last section; the total is derived from the heating value and rate of consumption of the gas. Both must, of course, be reduced to the same unit (*e.g.*, watts). When this is done the efficiency is expressible as a simple fraction or percentage, the unit of which is the most efficient light possible.

An alternative method of arriving at this figure is at hand when the total efficiency has been determined in lumens per watt or lumens per British thermal unit per hour. In this case it is only necessary to multiply the efficiency so expressed by the mechanical equivalent of light, which is 0.00159 watts per lumen, or 0.00543 B.t.u. per hour per lumen.

Since this total luminous efficiency is arrived at by taking into account all the convection and conduction losses, and the radiant luminous efficiency disregards these, it is possible, from the two measurements, to arrive at the *radiational efficiency* or efficiency of transformation of the applied energy into radiant energy. If we symbolize the rate of consumption of energy (power) by P, the rate of radiating energy by R, and the rate of radiating luminous energy by L, we have that the

$$\text{Total luminous efficiency} = \frac{L}{P}$$

$$\text{Radiant luminous efficiency} = \frac{L}{R}$$

$$\text{Radiation efficiency} = \frac{R}{P} = \frac{\frac{L}{P}}{\frac{L}{R}}$$

or the radiational efficiency is the quotient of the total luminous by the radiant luminous efficiency.

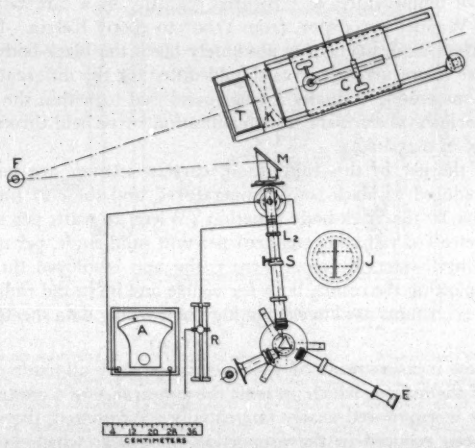
This method of obtaining the radiational efficiency assumes that the radiant luminous efficiency is the same in all directions from the source as in the direction measured, which is not in general accurately the case, although nearly enough so to get at a fair approximation. Other methods of arriving at the radiational efficiency will be treated below.

4. Measurement of Spectral Distribution of Emission.

(*a*) VISIBLE SPECTRUM.

The emission through the visible spectrum was measured by means of a spectro-pyrometer of the Hennings type, shown diagrammatically in Fig. 4. An image of the mantle or other surface to be measured (*F*) is formed by the mirror *M* and lens L_1, in

FIG. 4.



Spectropyrometer: *F*. Mantle. *M*. Mirror. L_1. Lens. *I*. Carbon incandescent lamp. L_2. Lens. *S*. Slit. *E*. Eye-piece. *J*. Appearance of spectrometer field. *A*. Ammeter. *R*. Rheostat. *C*. Carbon arc lamp. *K*. Lens. *T*. Water tank.

the plane of the carbon incandescent lamp *I*, and an image of this image and of the horizontal portion of the lamp filament is focused by the lens L_2 on the slit *S* of a small spectrometer. On observing the spectrum of the mantle at *E*, the eye-piece, it is seen crossed by a narrow band corresponding to the carbon filament. If a current is sent through the filament, its brightness may be varied until its matches that of the spectrum at any one color. The region of the spectrum to be used is limited to a narrow strip by an appropriate slit inserted in the plane of the eye-piece,

as shown in the enlarged insert *J*. The wave-lengths are read off the scale provided with the instrument.

In order to interpret the settings, which are in terms of current through the carbon lamp filament, the entire apparatus must be calibrated on a "black body." This was done by the aid of a Northrup resistance furnace. The spectro-pyrometer was, for this purpose, so placed that the mirror *M*, on turning through 90 degrees, was exactly over the top aperture of the furnace. Settings of lamp current were then made through the spectrum for a range of temperatures as measured optically by a carefully calibrated Wanner pyrometer, from 1100° to 2000° Kelvin. Unless the carbon lamp filament is absolutely black the black-body temperature lamp-current curves should differ for the different parts of the spectrum. Actually it was found that to within the limits of experimental error the same calibration curve held throughout the region 0.45μ–0.7μ.

By the use of this calibration, current settings are immediately reduced to black-body temperatures, and these in turn are reducible by the black-body equation (Wien) to watts per square centimetre (of radiating surface) per unit solid angle, per micron wave-length interval (0.0001 cm.), the unit employed throughout in plotting the results both for visible and infra-red radiation.

The constants used in calculating the working data sheets were

$$C_1 = 3.73 \times 10^4 \qquad C_2 = 14390$$

These measurements of visible emission were all made on the edge of the mantle, which presents the appearance of a continuous surface when viewed nearly tangentially. As plotted, the values have been reduced in the proportion of 1 : 1.2, which by photometric test represents the relative brightness of centre and edge. The results are therefore shown in terms of the porous centre, a method of plotting made necessary by the fact that the infra-red measurements had to be made on the centre of the mantle and the ratio of edge to centre radiance (not easy to determine satisfactorily) may differ from the distribution of brightness.

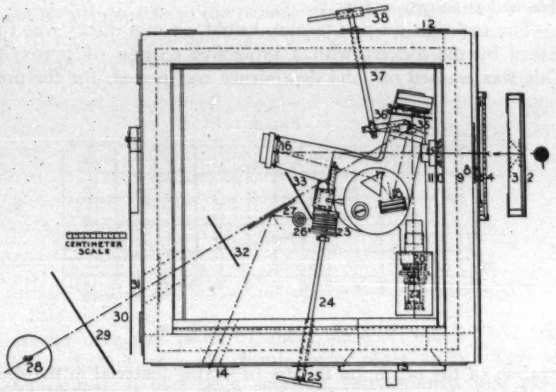
(*b*) INFRA-RED SPECTRUM.

The Spectrometer.

A Hilger infra-red spectrometer was used for the determination of the distribution of radiant energy in the long wave region.

This instrument, which is shown in plan in Fig. 5, is of the constant deviation type generally referred to as the Wadsworth mounting. Its essential parts, in their order along the optical path, are: incident slit, collimating mirror, rock-salt prism, plane mirror, emergent slit, linear thermopile.

FIG. 5.



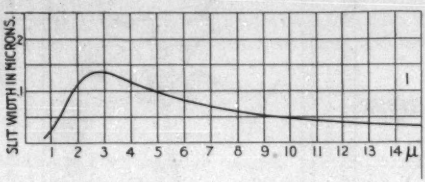
Infra-red spectrometer: 1. Welsbach burner with mantle. 2. Bright tinned sheet iron. 3. Cast iron screen. 4. Double walled shutter. 5. Slide over opening in *C*. 6. Bright sheet iron screen. 7. Lid allowing adjustment of slit. 8. Outer sheet iron wall. 9. Inner sheet iron wall. 10. Space bounded by two sheet iron walls filled with asbestos. 11. Cardboard. 12. Hinge. 13. Door admitting to thermocouple. 14. Window for observing drumhead. 15. Incident slit. 16. Collimating Mirror. 17. Rock salt prism. 18. Plane mirror. 19. Focussing mirror. 20. Emergent slit. 21. Thermocouple. 22. Microscope. 23. Wave-length drum. 24. Extended axis of wave-length drum. 25. Graduated disk for reading wave-lengths beyond 10. 26. Flashlight lamp. 27. Plane mirror. 28. Reference standard of radiation. 29, 32, 33, 34. Screens. 30. Shutter. 31. Window to admit radiation from reference standard. 35. Auxiliary mirror. 36. Supporting axis for mirror. 37. Key with arms, 38, to raise and lower mirror.

The settings and manner of use of some of these parts, as they were used in the present investigation, must be recorded in some detail. Starting with the slits: These were set at 0.5 mm. width throughout the work; their effective length is 10 mm. The value of this slit width in wave-length interval throughout the spectrum is shown in Fig 6. The plane and concave mirrors are of nickel-steel of a non-corroding formula, which, however, acquire a slight white coating on standing that rubs off easily. A knowledge of the reflecting power of these mirrors is, of course,

necessary for work of this kind. This was obtained from measurements on a plane mirror of the same material, furnished by the makers, whose reflecting power relative to that of a freshly deposited silver film was measured in the infra-red by the infra-red spectrometer and thermopile; in the visible and ultra-violet, by a quartz spectrometer and photo-electric cell with check measurements on a spectrophotometer. The reflecting power curve thus obtained is shown in Fig. 7.

The rock-salt prism (32 mm. height, 42 mm. face) was furnished by the makers with a protective coating of pyroxylin. This was washed off, and dependence was placed, for the pres-

FIG. 6.



Value of slit width in wave-length units.

ervation of the prism, on the use of drying material in the spectrometer enclosure. On several occasions some repolishing was necessary. No corrections for absorption in the rock-salt prism were considered necessary.

The thermopile is a linear one, Hilger design, consisting of ten bismuth-silver junctions, with a receiving surface 1 mm. by 10 mm., and a resistance of 2.5 ohms. It is mounted upon a bone base and attached immediately behind the emergent slit.

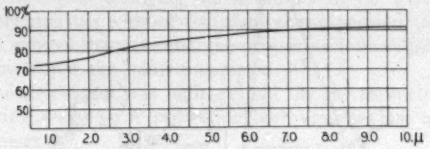
Wave-lengths are read upon the drum calibrated by the maker to 10μ. An extrapolation to 14μ was made upon the scale of the extension head going to the outside of the enclosure, to be presently described. A dispersion curve of the prism, necessary to reduce the deflections in the different parts of the spectrum to correspond to uniform wave-length intervals, was constructed from the maker's calibration of the drum.

For purposes of thermal and moisture insulation the whole spectrometer was placed in a galvanized iron box blackened on the inside, as shown in the plan, Fig. 5. The top and four sides

of this box were double-walled doors, and were stuffed with cotton, and extra double walls, 1.2 cm. apart, filled with powdered asbestos, completed the thermal insulation.

In order to maintain the dryness of the interior, calcium chloride and phosphorous pentoxide in open vessels were used. The outside edges of the doors were sealed by strips of electrician's tape, leaving, as the sole opening for direct communication with the atmosphere of the room, the incident slit. This could be adjusted from the outside after the removal of a small lid. It was also possible to close the opening to the slit by means of a small cork when the instrument was not in use.

FIG. 7.



Reflecting power of nickel-steel mirrors of infra-red spectrometer.

Great care was taken to shield the spectrometer box from direct radiation from the mantle under observation. This was accomplished in part by a sheet of bright-tinned iron placed about a centimetre away from the side of the box facing the radiation source. In addition the aperture (1 cm. diameter, round) which limited the area of the mantle surface observed was mounted on a thick iron plate (1 inch thick by 8 inches diameter), which in turn was protected by a sheet of bright-tinned iron facing the mantle and separated from the iron plate by about 0.6 cm. The shutter used to expose the spectrometer slit was for similar reasons made of double-walled bright tin with a layer of cardboard between.

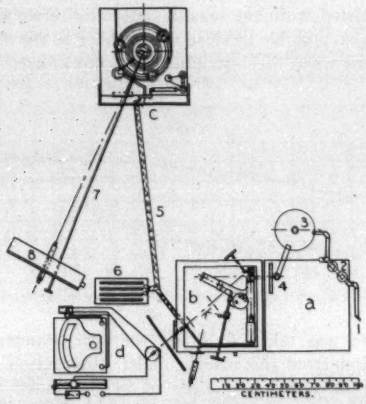
These precautions taken for thermal insulation secured steadiness under operating conditions, necessary and desirable because of the considerable time involved in carrying out all the measurements.

The use of this large insulating box made the wave-length drum inaccessible and necessitated some auxiliary means for turning it, which was provided by extending the axis through the

wall to an outside graduated disk. The drum itself was then read by a reading telescope through a glass window, the extrapolation beyond 10μ was made in terms of the external disk graduation.

An additional window to admit light from an auxiliary standard lamp, for calibrating purposes, and a mirror of ground glass,

FIG. 8.



Plan of infra-red set-up: *a*. Table supporting gas accessories: 1. Pipe leading to source of gas. 2. Pressure regulators. 3. Steadying capacity. 4. Welsbach burner. 5. Leads in sheath from thermocouple to galvanometer. 6. Resistance box. 7. Handle for control magnet. 8. Reading telescope and scale: *b*. Table supporting spectrometer and accessories. *c*. Suspension and support for galvanometer and accessories. *d*. Comparison radiation standard and accessories.

which could be turned into position, to reflect its radiation to the thermocouple, complete the spectrometer outfit.

The Galvanometer.

The thermocouple and a resistance box were connected in series to a Thomson galvanometer, shown in its relative position by the general plan, Fig. 8. The leads for this purpose were 115 cm. long, made of twisted lamp cord, passed, for purposes of insulation, through a rubber tube, placed in turn in an iron pipe.

The galvanometer was designed and built by W. W. Coblentz. The four coils were connected in parallel, giving a resistance of 2.5 ohms. For electrical and magnetic insulation, the galvan-

ometer was surrounded by a laminated iron cylindrical shell, close up, and by a series of three annealed soft iron pipes.

To use the galvanometer at all it was necessary to insulate it from mechanical shock. This was accomplished by mounting it upon a Julius suspension. The outstanding oscillations after this was done had an amplitude of only 0.2 or 0.3 mm. under good conditions, whereas, without the suspension, oscillations of several centimetres occurred.

Control of sensibility and zero position was secured, as is customary, by control magnets. The zero position was chiefly controlled, while observing, by a magnet beneath the galvanometer, turned by a long handle acting through two bevel gears. This control magnet could also be moved vertically, thus offering a ready means of changing the sensibility of the galvanometer over short intervals without disturbing the suspension. The other movable control magnets and the protective iron cylinders were all mounted upon the Julius suspension.

A wooden closet was built around the galvanometer and its accessories, serving for protection both against dust and aerial disturbances.

Calibration and Constants.

The sensibility of the galvanometer was determined by noting the deflection obtained when a Columbia dry cell was allowed to discharge through a specially constructed resistance furnished with the galvanometer. This resistance was placed in a glass tube, and the cell in a glass cylinder, sealed with paraffin. A bi-polar mercury contact, switch operated by the observer, controlled the circuit. The whole of the circuit was placed near the galvanometer and within the galvanometer enclosure.

The sensibility of the galvanometer most frequently used through this investigation was that when the period of the galvanometer was about 4 seconds. For special purposes the sensibility could be increased three- or four-fold. This could be maintained with difficulty, and for a short time only, on account of marked drift of the zero position. This drift is due chiefly to thermal conditions, but probably also to electrical and mechanical ones.

With the period of four seconds the drift was 3 or 4 cm. per hour, and under the best conditions somewhat less. The current

sensibility of the galvanometer with a period of 4 seconds, as determined by the special circuit described above, was 0.37×10^{-10} ampères per millimetre deflection with the scale at one metre. The sensibility of the galvanometer, when adjusted for any given period, could be decreased by addition of resistance in series with it. This was done for the points in the spectrum of maximum energy—as much as 250 ohms being required at times to keep all deflections comparable. Linearity for small deflections was proved by the use of a sector disk.

On account of the drifting of the zero, and on account of certain uncontrollable thermal and electrical changes in the environment, all of which produced variations in the sensibility of the galvanometer, it was necessary to be able to ascertain the sensibility, irrespective of the position of the zero on the scale, and irrespective of the amount of resistance in the galvanometer circuit. For this purpose a 100-candle-power stereopticon point-source carbon filament lamp was mounted outside the spectrometer enclosure in front of a window into the enclosure.

A mirror, already mentioned, mounted near the focusing mirror formed an integral part of the spectrometer and reflected the radiation from this lamp on the thermopile. The mirror and the shutter which controlled the illumination on the mirror could be operated by the observer. The sensibility could thus be determined very readily at any instant. The carbon lamp was always operated at 100 volts, which gives approximately 4.85 watts per cm.^{2} per steradian.

Observational Procedure.

The burner and mantle were placed at a distance of about 10 cm. from the incident slit and immediately in front of the thick cast-iron plate and diaphragm already mentioned. The gas pressure was maintained at 3 inches by a governor near the burner. To eliminate slight effects which might escape the governor, a large capacity in the form of a 5-gallon tin can was inserted between the governor and the burner outlet.

Observations were made at intervals of 0.1μ for the most part; in a few cases intervals of 0.2μ were sufficient in the longer wave-length, while intervals of 0.01μ were necessary in the short wave-lengths in some instances. Five or more readings were necessary at every point to obtain values that could be successfully duplicated. With each sensibility employed a deflection was

taken for the comparison standard radiation, and the mantle deflections were reduced to this standard deflection as a unit. With the "100-candle-power" stereopticon lamp used, at 100 volts (4.85 watts per cm.^{2} per steradian) this deflection unit corresponded to a sensibility of 0.329×10^{-10} ampères.

The observations by means of the infra-red apparatus extended through the region of the spectrum from 0.8μ to 14μ. Only on a few occasions could observations be made at shorter wave-lengths. There is thus a region from 0.7μ (end of visual work) to 0.8μ in which there are no observations, and which must be filled by extrapolation.

Reduction of Observation.

The observations as made all had to be reduced in accordance with the dispersion curve of the prism and the reflecting power of the three nickel-steel mirrors. After the reduction they gave *relative* energy value through the spectrum.

To give these relative spectral energy curves an interpretation in terms of ordinary units of energy and to compare them with the results given by total energy measurements determined by means of a surface thermopile, the following procedure was adopted:

The spectral energy curve of the ordinary Welsbach mantle was determined. The area of this curve, multiplied by the factor sought, was equated to the total energy so obtained, giving watts per cm.^{2} per micron, per unit solid angle as 0.0018, for the present set-up.

As a check on this a black-body furnace with an aperture of 3 mm. diameter was placed before the slit. The curve for the black body so obtained compared in relative values throughout the spectrum to 9μ satisfactorily with the black-body curve computed with the above constant.

5. Measurement of Mantle Temperatures.

A knowledge of the temperature of the mantle is of great importance. By use of the temperature it becomes possible to fix the emissive power or ratio of the emission to that of a black body at the same temperature. Without this knowledge it would be impossible to determine, except crudely, the exact characteristics of the mantle itself, irrespective of the particular tempera-

ture at which it is operated. Lack of temperature data has indeed been one of the chief deficiencies of much spectral emission work.

The exact determination of mantle temperatures is by no means an easy task. The temperature varies greatly from point to point, especially from top to bottom of the mantle (as much as 300°), and also from mantle to mantle, depending on adjustment, the way in which the mantle hangs, its age, etc. In order to reduce the range of possible uncertainty the regular temperature measurements made in this study were carried out as nearly as possible uniformly on the same part of the mantle, one-third the distance up from the bottom.

Three methods of temperature measurement were studied: (*a*) Optical, (*b*) by thermocouples, (*c*) by total radiation, as described below.

Of these, the most satisfactory was the second or thermocouple method, upon which chief reliance was placed, although the other methods gave support and confirmation when applicable.

(*a*) OPTICAL METHOD.

The optical method of measuring mantle temperature was employed by Rubens. He used it, however, in a manner which could only lead to correct results with a completely opaque, completely absorbing body, which the mantle is not, although the mantles rich in ceria approximate this condition in the blue end of the spectrum, to which Rubens confined the temperature observations on which he placed reliance. The method consists in general in measuring the black-body temperature by the usual method of equality of brightness used in the Holborn-Kurlbaum and Henning pyrometers, and then deriving the true temperature from a knowledge of the optical properties of the observed radiator.

If r_λ is the reflecting power of the body at wave-length λ, t_λ its transmitting power, E_λ its radiant emission, and J_λ the radiant emission of the black body at the same temperature, we have, from Kirchoff's law, that

$$E_\lambda = J_\lambda (1 - r_\lambda - t_\lambda)$$

provided the surface under study is continuous. If it is discontinuous (as, for instance, a grid of fine fibres would be), we

have, if s represents the fractional part of the area occupied by the solid material, that

$$E_\lambda = J_\lambda \, s \, (1 - r - t_\lambda)$$

Using Wien's law, this gives us for the true temperature T, in terms of the apparent or black-body temperature T_a

$$\frac{1}{T} - \frac{1}{T_a} = \frac{\lambda}{c_2 \log e} \log s \, (1 - r_\lambda - t_\lambda)$$

In this formula the constants s, r, and t, refer, of course, to the properties of the *hot* body. It appears from the equation that T and T_a are more nearly the same the shorter the wave-length.

It is obvious that accurate temperature determination by this method would demand very elaborate measurements to establish the hot porosity, reflecting and transmitting powers. The best condition for using the method holds at the edge of the mantle, where by projection it appears continuous. Here s approaches the value unity. Also, by working near the edge of the mantle, r (cold) reaches its nearest approximation to the reflecting power of a thick opaque layer of the material in powdered form—which is capable of accurate measurement—and from which, by measurement of a bright image formed on the hot and cold mantle, the hot reflecting power is derivable.

The possibility of obtaining accurate results from the edge of the mantle, by assuming $t = 0$ and $r =$ the reflecting power of a solid layer of material, only exists if the assumptions are approximately correct. They will be so in the case of strongly absorbing substances, but it appears, from experiments made to test this point with various mixtures of thoria and ceria, that these assumptions are far from holding with most mantles. Thus in a series of mantles made up with continuous patches, formed by sewing small rectangles of filter-paper on the mantle fabric, it was found that when such a continuous patch was of such weight that when viewed normally it appeared upon measurement to have the same reflecting power and other optical properties as the edge of the mantle, it had a reflecting power, if of pure thoria, of only 0.55, while the solid material has a reflecting power of 0.85. Moreover, upon examining the brightness of the patch when illuminated both upon the illuminated and unilluminated sides, the latter was found to be over 50 per cent. of the former, showing that a very large part of the incident light is transmitted, even by the edge of the mantle. Thus neither can r be taken as that of the

continuous layer of the mantle material, nor can t be taken as negligible, even when conditions are such as to make s = unity.

It therefore appears, as is borne out by our complete data, that the optical method, which should give accurate results for opaque layers of radiating material, is not practically applicable to mantles in general. The method gives substantially accurate and consistent results (as judged by the thermocouple readings) for mantles high in ceria in the yellow form throughout the shorter half of the visible spectrum, since in this case the cold material is fairly opaque in thin layers, and the mantle reflecting power cold is not greatly different from that of a solid layer. In the regular 99 per cent. thoria and 1 per cent. ceria mantle the black-body temperature and the temperature as corrected by inserting the hot reflecting power (ratio of hot to cold reflecting power × cold reflecting power of mantle material in continuous layer as above described), and neglecting its transmitting power, when determined for the extreme blue, differ from each other and the thermocouple temperature by amounts less than the uncertainties of the latter measurements. In the case of the pure thoria mantle, however, the nearest approach to the true temperature that the method gives, even if r and t are assumed to amount together to the reflecting power of an opaque layer, namely, 85 per cent., falls short of the thermocouple temperature by as much as 100°. This failure is in part due to the error in the value of r and t assumed for the cold mantle, and in part perhaps to an actual increase of transparency with increase in temperature. In either case accurate results could be attained only by measuring the true reflecting and transmitting powers of the heated mantle—a task of very great complexity and difficulty.

(*b*) THERMOCOUPLE METHOD.

The most satisfactory method of temperature measurement, on the whole, is that which utilizes a series of thermocouples of graduated size, first used by Nichols for flames, and later by White and Travers [6] for the incandescent mantle. The theory in its simplest form is that, while a single thermocouple will not give correct readings, due to the heat it radiates and conducts away, this error is less the smaller the couple, and so by using a series of decreasing size the value which would be given by a couple of zero mass may be fixed by extrapolation.

Our temperature measurements were carried through with couples of platinum-platinum-rhodium of diameters 0.35, 0.25, 0.15, and 0.05 mm. secured from Engelhardt, and drawn from the same stock. One of these was calibrated by the Bureau of Standards, and the calibration was assumed to hold for all. Certain precautions were observed in their use, some obvious and some learned from experience. As great a length as possible of the couple should be against the mantle, so that the temperature at the junction is affected a minimum amount by conduction to the cooler portions not in contact. The "bead" should be as nearly as possible of the same diameter as the wires which it joins, so that the diameters assigned in plotting shall be correct. After continued use the couples may give inconsistent results, as though one or more had become contaminated in some way. Upon cutting off the beads and forming new ones the trouble is usually overcome.

It has ordinarily been assumed that the points given by such a series of thermocouples lie on a straight line. Our results on the couples described indicate rather consistently that these points lie on a curve. Some representative results are shown in Fig. 9 (*I*) for mantles of several temperatures. The curvature spoken of is well shown, and it appears as well that with the lower temperature mantles the curve is more nearly perpendicular to the temperature axis; *i.e.*, the various couples differ less in their readings.

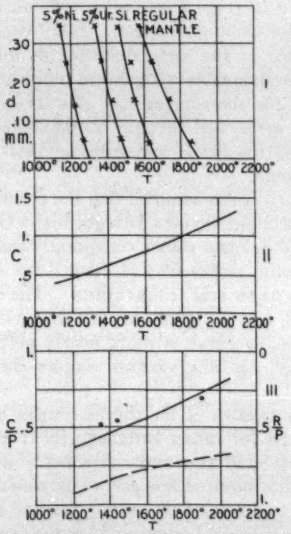
These characteristics of the thermocouples of varying diameter are accounted for rather satisfactorily if it is assumed that they may be considered as cylindrical wires to which heat is conveyed through thin films of hot gas, of thickness independent of the temperature and size of the wire. Similar assumptions have been shown to be valid by Langmuir [7] for the case of heated wires losing their heat to a surrounding atmosphere at a much lower temperature. The thickness of the effective gas film in that case, namely 0.43 cm., is too great to be assigned easily to the thermocouple against a mantle, and if a much smaller thickness is assumed it becomes necessary to obtain independent experimental proof of its effective constancy of thickness, especially under the very different temperature differences in question. The possibility for such a theoretical support of the character of the curve needs merely be noted here; for the present purpose it is

sufficient to utilize the experimental fact that satisfactory temperature measurements are obtainable from a series of couples by extrapolation.

(c) RADIATION METHOD.

It was found experimentally, from the measurements made on the total radiation from mantles, that the radiation for con-

FIG. 9.



I. Measurement of mantle temperature by thermocouples of graduated diameter: *d*. Thermocouple diameter. *T*. Temperature.
II. Relative convection losses at various temperatures as calculated from the conducting film theory: *c*. Convected energy.
III. Convection losses as calculated from specific heat of products: *C*. Convected energy. *P*. Applied energy. *R*. Radiated energy. Full line—Combustion in air. Dashed line—Combustion in oxygen.

stant gas consumption was not constant, *but decreased with increasing mantle temperature*. Thus a black bulb thermometer placed so as to be heated in turn by the radiation from mantles of various compositions would exhibit the apparent anomaly of showing the greatest temperature rise for the mantle of lowest

temperature. A relationship of this sort, besides demanding explanation, offers a possible method of temperature measurement.

The explanation lies in general in this fact, that for a given constant consumption of gas (rate of supply of energy) the portion of the total power which is dissipated by convection and conduction is greater the higher the temperature, consequently the rest of the applied energy, which can escape only as radiation, must be smaller the higher the temperature. The behavior of the complete burner-mantle combination may be handled in two different ways. One way is on the assumption, found well confirmed by Langmuir, that the convection of heat away from a surface takes place as though there were a stationary film of gas, of thickness independent of the temperature of the surface, through which the heat is carried entirely by conduction. The second way is to consider the products of combustion as leaving the surface of the mantle at the mantle temperature, and then from the specific heat of these products to calculate the heat thus carried away. In each case the radiation is the difference between the energy consumption and the convection-conduction loss.

Taking up the first mode of treatment, if we call the thickness of the gas film t and its conductivity K, and if the temperature of the mantle surface is T_m and that of the surrounding atmosphere T_a, we would have for the energy conducted away, C, if K were a constant.

$$C = \frac{K}{t}(T_m - T_a)$$

Actually K is not a constant, but varies with the temperature; it is therefore necessary to substitute for kT the quantity $\int_o^T k\,d\vartheta$ which may be called ϑ so that we have

$$C = k_1(\vartheta_2 - \vartheta_1)$$

where k_1 is a constant. Now values of ϑ in energy units have been calculated by Langmuir for hydrogen, air, and mercury vapor, the curves connecting T and ϑ being of similar shape but different absolute value for these three gases. Upon taking the values for air, assigning the value 300° K. to ϑ, and using temperatures from 1100° to 2100° K. (range covered by ordinary mantles), the data shown in Fig. 9 (II) are obtained. It will

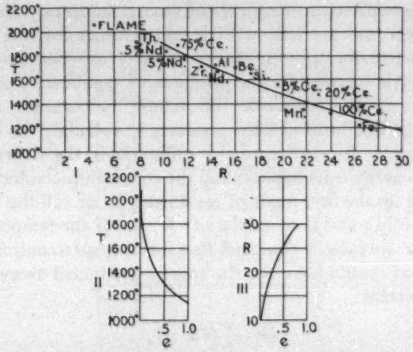
be seen that these differ but little from a straight line. The radiation R will be as stated above—

$$R = P - C = P - A\,(T_m - T_a)$$

where P is the applied energy, so that if P is a constant, R will be represented as a very closely rectilinear function of T_m, the mantle temperature.

The second method of treatment is considered at length below in connection with the question of the total efficiency of the mantle and burner. For the present purpose it is only necessary

FIG. 10.



I. Experimentally found relation between temperature and radiance: R. Radiance in arbitrary units. T. Temperature.
II. Relation between emissive power and temperature: ε. Emissive power. T. Temperature.
III. Relation between emissive power and radiation: ε. Emissive power. R. Radiance, in arbitrary units.

to refer to Fig. 9 (III) to see that this same nearly rectilinear relation between temperature and convection losses is indicated, and hence the same form of relation between temperature and radiation.

Experimental confirmation of this relation is shown in Fig. 10 (I) where total radiation measurements are plotted against temperatures as found by the thermocouple method. In view of the fact that the linear relationship is only to be expected if the consumption is constant, and if the mantle forms the outer surface of the heated "body," and that actually the mantles were ordinarily adjusted to give the maximum luminosity, irrespective of

exact consumption, or whether the flame did or did not strike through the mantle—which, moreover, is not a continuous but a porous body—the agreement with the theoretical treatment is good. The straight line fixed by several well-determined thermocouple points thus constitutes a plot from which temperatures may be determined from radiation measurements.

As a further step an emissive-power-temperature relationship follows from the same data, for, if e is the emissive power, and the Stefan-Boltsmann constant, R the radiation

$$R = e\sigma\,(T_m^4 - T_a^4)$$

or

$$e = \frac{R}{\sigma\,(T_m^4 - T_a^4)}$$

Now, R and T both being given in the plot of Fig. 10 (I), e as a function of T is readily calculated, giving a relationship of the form shown in Fig. 10 (II), which is plotted through the measured emissive powers as determined by the direct methods already described.

A point of some interest is brought out by developing the relation between emissive power and radiation, upon substituting T_m in terms of R and P, which give

$$e = \frac{R}{\sigma\left[\left(T_a - \frac{R-P}{A}\right)^4 - T_a^4\right]}$$

This relation shows that e may be expressed as a function of R as the only variable. Fig. 10 (III) shows the relationship plotted from the previously used data.

Under the conditions holding in the mantle, therefore, with its constant rate of supply of energy, the smaller the radiation the higher the temperature and the lower the emissive power, and once the constants in the relationship have been established, the single measurement of radiation establishes the value of all three quantities.

Obviously, from the experimental data shown, the conditions holding with the various mantles are not uniform enough to make the radiation measurement in combination with the plotted mean curve a precision method of temperature or emissive power determination. It does, however, give a useful check on other measurements, and has been found valuable in that way. For

instance, a series of infra-red emission curves, made upon a series of similar mantles composed of graduated mixtures of two oxides, may be assigned their relative temperatures very satisfactorily from their areas. The method of fixing emissive power by a radiation measurement is capable of application to the study of substances in some other than mantle form.

6. Measurement of Reflecting Power.

Some of the oxides studied showed the interesting property of changing their optical properties on heating. In other cases mixtures of oxides showed color characteristics different from that of their constituents. In order to record these properties measurements were made through the visible spectrum (1) on the reflecting power of the mantle material cold, in powder form, and (2) of the change of reflecting power of the mantle upon heating.

The cold reflecting power of the mantle material was measured by means of a spectrometer and potassium photo-electric cell. All measurements were made in terms of magnesium oxide as a standard white, two shallow cups being provided which could be alternated before the spectrometer slit, and which, when in that position, were illuminated by the focused image of a concentrated filament tungsten lamp. In order to reduce the reflecting power to absolute values the diffuse reflecting power of magnesium oxide has been taken as 85 per cent.

For the measurement of the change of reflecting power upon heating, the spectropyrometer previously described (Fig. 4) was employed, in conjunction with a carbon arc lamp, *C*, used to give an image of the carbon crater for projection on the mantle. The carbon arc image was formed by a projection lantern condenser, the light passing through a water tank, and falling on the edge of the mantle under observation, the line of projection being made as nearly coincident with the line of observation as possible.

The procedure found best by trial was first to set the spectropyrometer on the incandescent mantle, taking the reading; then with the mantle unlighted to adjust the arc image until it matched in brightness the pyrometer lamp as held to the mantle value; finally, the mantle was again ignited and a setting made on the mantle and arc image combined brightness. From these three settings it is at once possible by translating the black-body

temperatures into intensities, to obtain the hot reflecting power in terms of the cold.

7. *Determination of Emissive Power.*

In order to obtain the emissive power of a substance it is necessary to know its radiant emission and its temperature, from which the radiant emission of the black body at the same temperature may be calculated, thus giving the two quantities whose ratio is desired.

The total emissive power is given by combining total radiation measurements made as previously described, in absolute measure, with the corresponding emission of the black body as calculated from the temperature. In the case of the wave-length distribution of emissive power, one possible process would be to make observations on a black-body opening subtending the same angle as the measured portion of the mantle. From this observation black-body emission curves could be constructed for other temperatures, and comparisons then made wave-length by wave-length. Another process is to measure the area of the normally plotted emission curve and then draw on the same wave-length scale the emission curve of the black body at the mantle temperature with such ordinates that the area of mantle and black-body curves is as found by the radiation measurements. The ratio of the curves at each wave-length gives the desired emissive power.

In the visible spectrum the emissive power is obtained at once from the optical pyrometer measurements by comparing the brightness pertaining to the apparent black-body temperature to the brightness of the black body at the true temperature of the mantle. With ideal precision of measurement, or such an approach thereto as could be obtained if both infra-red and visible measurements were made simultaneously and conditions were exceedingly steady for the infra-red end, it should be possible to make readings in the red end of the spectrum overlap, whereby the comparatively easy determination of emissive power in the visible region could be made to serve as a starting-point for the continuation into the infra-red.

Actually the method upon which most reliance was placed was the second, but a reasonably close agreement of the infra-red and visible emission measurements at their junction point when

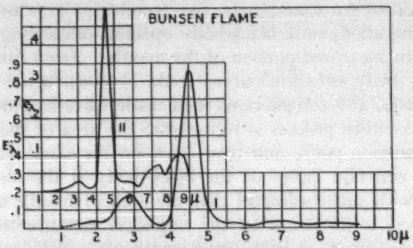
corrected to the same temperatures was demanded (so as to be within the possible temperature and other variations in making either sets of observations) before these were reduced to emissive powers.

The emissive power wave-length curves as plotted are all referred, as in the case of the emission curves, to the porous centre of the mantle.

8. List of Quantities Measured in Complete Study.

The routine measurements made on each mantle were eight in number, and may be tabulated here, before the detailed discussion of each mantle is undertaken.

FIG. 11



I. Spectral distribution of emission in the Bunsen flame.
II. Spectral distribution of emissive power in the Bunsen flame.

The various measurements are as follows:

1. Temperature, T, in centigrade degrees absolute (Kelvin).
2. Total radiation, R, in watts per cm.^{2} per steradian (radiance).
3. Total emissive power, e.
4. Radiant luminous efficiency, $\frac{L}{R}$.
5. Spectral distribution of radiant emission E_λ in watts per cm.^{2} steradian per micron wave-length interval.
6. Spectral distribution of emissive power, ϵ_λ.
7. Spectral distribution of reflecting power of mantle material, π_λ.
8. Ratio of reflecting power hot, to reflecting power cold, $\frac{r^h}{r^c}$.

V. CHARACTERISTICS OF THE BUNSEN FLAME.

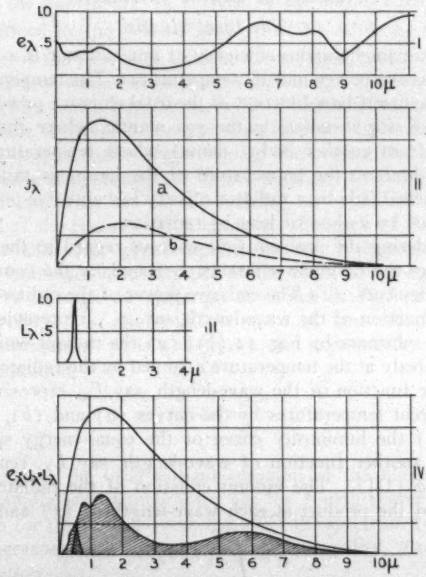
The Bunsen flame, as the "base" and source of heat for all the mantles, and hence always present, must claim first attention

among mantle materials, although itself of negligible value as a light-source.

The values of the tabulatable quantities are as follows:

T	R	$\frac{L}{R}$	
2050°	.43	Negl	0.0116

FIG. 12.



Diagrammatic representation of selective temperature radiation:
I. Spectral distribution of emissive power in an assumed substance.
II. Spectral distribution of emission for a black body at high (*a*) and low (*b*) temperatures.
III. Luminosity curve of the equal-energy spectrum.
IV. Emission (cross-hatched curve) and luminous emission (double cross-hatched curve) of radiator I, at temperature which gives black body emission at (II).

The spectral distribution of radiant emission is shown in Fig. 11 (I). It is characterized by maxima at 1.95μ, 2.9μ, 4.52μ, 5.6μ, 7μ, and 8.35μ, of which the one at 4.5μ (CO_2) is the most conspicuous. This band is a characteristic feature of all mantles heated by the flame.

In the same figure, on a different scale, is shown (II), the emissive power distribution e_λ, which is everywhere low except for the band at 4.5μ, which is high, but because of its narrowness does not contribute enough to make the flame other than a very poor radiator.

VI. GENERAL THEORY OF MANTLE LUMINOSITY AND METHOD OF CLASSIFYING MANTLE MATERIALS.

1. The Ideal Mantle.

The radiant luminous efficiency of any radiator is a function of its emissive power and its temperature. The temperature attained may itself be a function of the total emissive power. This is the case, for instance, in the gas mantle, where the heat is supplied from another body (flame) whose temperature places an upper limit to the temperature of the luminous radiator, to be approached only by a radiator of very low emissive power, but little cooled by its loss of heat by radiation.

Considering the problem first without regard to the method of heating, the luminous efficiency is found by the combination of three elements: (1) The emissive power of the radiator, which is some function of the wave-length, say, e_λ, represented for an arbitrary substance by Fig. 12 (I); (2) the radiant emission of the black body at the temperature assumed by the radiator, which is another function of the wave-length, say J_λ, represented for two different temperatures by the curves (*a*) and (*b*), Fig. 12 (II); (3) the luminosity curve of the equal-energy spectrum, which is another function of wave-length, say L_λ, represented in Fig. 12 (III). The radiant emission of the radiator is the integral of the product at each wave-length of (1) and (2) or

$$R = \int_0^\infty e_\lambda J_\lambda d_\lambda$$

represented by the cross-hatched curve, Fig. 12 (IV).

The luminous emission is the integral of the product of each wave-length of (1), (2), and (3), or

$$L = \int_0^\infty L_\lambda e_\lambda J_\lambda d_\lambda$$

represented by the double cross-hatched curve, Fig. 12 (IV).

The luminous efficiency of the radiated energy is now

$$\frac{L}{R} = \frac{\int_o^\infty L_\lambda e_\lambda J_\lambda d\lambda}{\int_o^\infty e_\lambda J_\lambda d_\lambda}$$

Of the factors in this equation, L_λ is fixed by the characteristics of the human eye, J_λ is fixed by the absolute temperature, being defined by the Wien-Planck equation, while e_λ is a characteristic of the substance used in the radiator, and may in general have any value between zero and unity. The two underlying factors which may be varied in a luminous radiator therefore reduce to *temperature* and *composition*. In so far as temperature is concerned—neglecting for the present the limitations to attainable temperature set by the manner of heating, and the practical limitation set by the melting or volatilization of the material of the radiator—the luminous efficiency of the radiator increases with very great rapidity as this is increased. This follows from the characteristics of the black body, whose emission curve through the spectrum as shown in Fig. 12 is always the "envelope" of the emission curve of any radiator at the same temperature. As is well-known, and expressed by the Wien-Planck equation,

$$J_\lambda = C_1 \frac{\lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}$$

not only does the total radiant emission of the black body increase rapidly with temperature (as the fourth power), but the emission for the shorter wave-region of the spectrum (the visible end) increases with by far the greater rapidity, according to the equation:

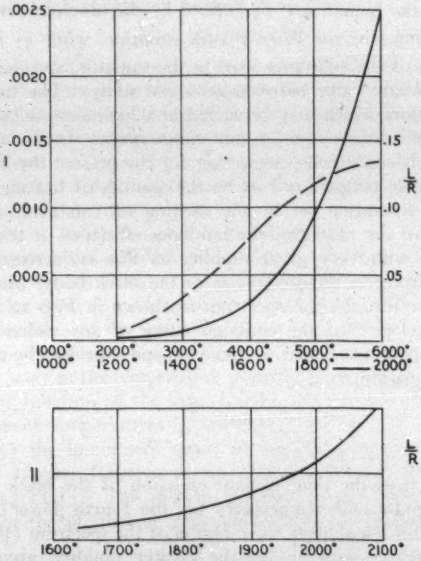
$$J_\lambda = C_1 \lambda^{-5} e^{-\frac{c_2}{\lambda T}}$$

which in the case of visible energy, for temperatures around 1800° K., is equivalent to the thirteenth power of the temperature. Consequently, as the temperature increases, the short wave (visible) energy emission is favored. Hence, with any radiator whose emissive power has finite values throughout the whole spectrum, the greatest luminous efficiency is attained at high

temperatures. Fig. 13 (I) shows the relationship between luminous efficiency and temperature for a black body, which reaches its maximum (13.5 per cent.) at about 6500° K.

Considering next the effect of the spectral distribution of emissive power of the radiator, it is obvious that no radiator

FIG. 13.



I. Radiant luminous efficiency of the black body at various temperatures.
II. Relative radiant luminous efficiency of the regular mantle at various temperatures obtained by oxy-gas heating.

promises improvement in light-production unless it has an emissive power in the visible region of the spectrum, *relatively* high as compared with the rest of the spectrum. If it is the same as elsewhere in the spectrum, the body is gray; *i.e.*, it has the same efficiency as the black body, which is lower, at temperatures now available, than many light-sources in use. The ideal to be sought from the standpoint of light production is a radiator which

shall have *no* emissive power except in the visible region, and maximum emissive power there, preferably, if mere efficiency is desired, all concentrated on the wave-length of maximum visibility. Were such a radiator attainable, it would have maximum (unit) radiant luminous efficiency, irrespective of temperature. This ideal is not in sight at present, but a radiator which approximates in any degree thereto is more efficient than a black body at the same temperature, and, like it, increases in efficiency with increased temperature. The increase in efficiency may be more or less rapid than with the black body, depending on the values of e_λ.

There is a second reason for aiming toward a spectral emissive power distribution of the ideal type discussed, which is in a way peculiar to the method of heating employed by the gas mantle. This is that by this type of emissive power the temperature attained by the mantle by contact with the flame approaches most nearly the upper limit set by the temperature of the flame. This follows at once from the consideration that the lower is the emissive power as a whole the less loss of heat there is from the mantle by radiation, and hence (*provided this gain is not offset by increased convection or conduction losses*) the higher the temperature it can maintain.

From every standpoint, therefore, it is clear that the desirable mantle materials, in so far as radiating properties are concerned, *are those of high emissive power in the visible region, of low emissive power elsewhere.*

2. Radiation from Mixtures of High and Low Emissive Powers.

Fortunately for the gas-mantle industry, the available materials have not been restricted to single refractory compounds possessing the characteristics just outlined. It has been found possible to obtain in *mixtures* properties which neither material possess alone, or, put differently, to obtain in some degree a combination of the desirable qualities of several materials, to the partial exclusion of their undesirable ones. Such mixtures consist, as a rule, of an oxide having low general emissive power in the visible region (base), combined with one having high emissive power in the visible region (*colorant*). The proper proportion of the mixture is that which secures the optimum

luminous efficiency: as conditioned on the one hand by the rise of visible emissive power due to the colorant, on the other hand, by the drop in the temperature assumed by the mantle in the flame due to the increasing radiating power of the mixture as the amount of colorant is increased.

It is a general characteristic of such mixtures that their luminous efficiency rises to a maximum and then decreases as the amount of colorant is continuously increased. This may be illustrated by a simple hypothetical case. Let us imagine a highly transparent base of low radiating power, which gives no light (*i.e.*, visible emission), upon which black particles are sprayed. Before the addition of the black particles the base, because of its low emissive power, assumes very nearly the temperature of the heating flame. The first few black particles, assuming practically this temperature, glow brilliantly. Now as more particles are added the effective radiating surface increases, with consequent more light. But, at the same time, the temperature of the mixture is pulled down by the increased radiation, so that the luminous efficiency of the black particles decreases. The mixture-light curve is hence the resultant of two opposing effects. For the case considered it may be approximately calculated in terms not of mixture proportions, but of effective radiating area of black particles, which is, of course, a function of mixture proportions. Thus, if we assume, for the sake of simplicity, that the total energy radiated by the assumed mantle is constant (instead of increasing with decreased temperature), we have that its temperature for any black radiating area a is given by the relation:

$$(a+a_0)\, T_1^4 = a_0 T_0^4$$

$$\frac{T_1}{T_0} = \sqrt[4]{\frac{a_0}{a+a_0}}$$

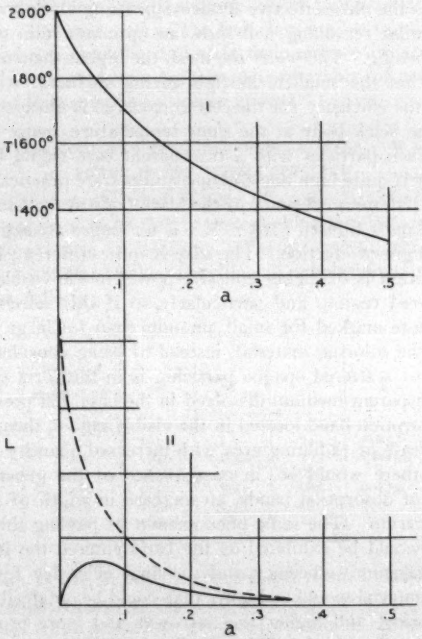
where a_0 = emissive power of base, T_0 the temperature assumed by the base, and T_1 the temperature assumed by the mixture.

Now the luminous value of these black particles is given by the light emitted by the black body at the temperature of the mixture, which is known, times the radiating area of the particles. The various steps of this calculation are shown in Fig 14, I and II. In I is shown the variation of temperature with a, assuming the base of emissive power 0.1 to take the temperature of 2000° K. in the flame. In II are shown (dashed line) the

luminous value of the black body at temperatures of 2000° and below, and (full line) the product of a and L against a, L being taken for the appropriate temperatures as given by I.

It is shown by this calculation that with the assumed constituents a luminous efficiency (light-output to energy output)

FIG. 14.



Theory of mantle luminosity:
I. Decrease of temperature with increase of emissive power.
II. Variation of luminous emission with increase of emissive power.

can be secured higher than either constituent—represented by the values 0 and 1 of a—can give. In the last analysis this will be found in the case of the black-body colorant assumed to be merely a consequence of the fact that, while the total radiation varies as the fourth power of the temperature, the luminous radiation

varies as the eleventh or twelfth power of the temperature in the region near 2000° K. In other words, it is more economical, from the standpoint of light-production, to use the heat available for heating a small quantity of matter to a high temperature than a large quantity to a low temperature. Given a limitation of temperature and available energy, the kind of mixture assumed constitutes the most effective mode of utilizing black-body radiation. Similar reasoning will show an optimum ratio of mantle fibre to opening. The wider the mesh the higher the temperature assumed, but the smaller the light-giving surface. It is easily seen that the efficiency for the case considered is always less than that of the black body at the same temperature, hence the mixture of black particles with a transparent base would be of interest only if quite high flame temperatures were practically available—the luminous efficiency of the black body at the temperature of the ordinary Bunsen (2050° K.) is no longer attractive in the study of light-production. The case is quite different, however, if the colorant is of higher emissive power in the visible than in the infra-red region, and particularly so if this selective character is more marked for small amounts than for large. If, for instance, the coloring material, instead of being considered as in the form of scattered opaque particles, is in the form of a generally transparent medium dissolved in the base, but possessing a single absorption band located in the visible region, then, in place of an increase of radiating area with increased quantity as above assumed, there would be, in consequence of the general characteristic of absorption bands, an increase in width of the band in the spectrum. The same phenomenon of passing through an optimum would be exhibited as the band entered the infra-red, but the maximum efficiency and the final efficiency for such a coloring material would be higher than could be obtained by mere black coloring, and higher the narrower and more pronounced the absorption band. It will be seen below that the regular thoria-ceria mantle conforms closely to the kind of mixture just described. It follows from this reasoning that any colorant—*i.e.*, any material of relatively high visible emissive power, short of the ideal material discussed previously—is most efficiently utilized in a flame of fixed temperature if it can be mixed with a certain proportion of material of considerably smaller emissive power.

3. *Classification of Mantle Materials.*

A rather definite basis of classification of the mantle oxides here studied may be made according to whether they possess high or low emissive power in the visible spectrum. If their emissive power is low they are either of no use in light-production or are of use as bases for coloring materials. If their visible emissive power is high they are of promise either alone or as coloring materials. The materials of the first class are best studied alone. The second class must be studied in their series of mixtures, with bases of low general emissive power—preferably, of course, with the base of lowest emissive power known.

VII. MANTLES COMPOSED OF OXIDES OF RELATIVELY LOW EMISSIVE POWER IN THE VISIBLE SPECTRUM.

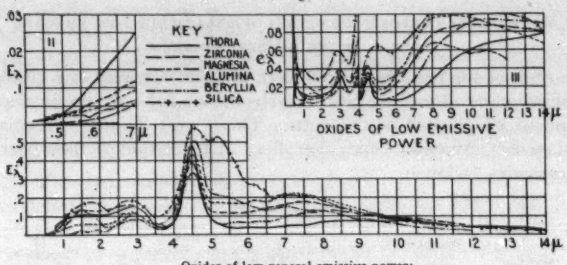
Six of the mantles studied were of such relatively low visible emissive power as to be clearly useless alone for light-production, and of no promise as colorants. These were Thoria, Zirconia, Magnesia, Alumina, Silica, Beryllia. A tabulation of their characteristics follows:

Material	Weight of mantle, grammes per cm.^{2}	T	R	ϵ	$\frac{L}{R}$	$\frac{L}{R}$ Compare to BB at same temperature
ThO_2.....	.0090	1930°	1.1	.044	.00032	.2
ZrO_2.....	.0060	1670°	1.32	.095	.000143	.36
MgO.....	.0082	1840°	1.1	.053	—	—
Al_2O_3.....	.0065	1725°	1.41	.088	.00039	.7
SiO_2.....	.0046	1650°	1.71	.13	—	—
BeO.....	.0032	1690°	1.61	.11	—	—

In Fig. 15 are shown the spectral emission, I and II, and the spectral emissive power, III, of these six mantles. It will be noted that, while this whole group of mantles is characterized by low visible emissive power, all giving very little light, they yet differ very widely in their total emissive powers and the temperatures which, as a consequence, they maintain in the flame. At one extreme lies Thoria, which assumes a temperature of 1930°, 120° below that of the flame. Next to it, but much inferior, lies Magnesia, with a temperature 90° lower. At the other extreme lie Silica and Beryllia, assuming temperatures of

1650° and 1690°. These latter are striking examples of substances possessing properties almost exactly complementary to those desired in light-production, for both by the low temperature assumed and by the distribution of emissive power with all the higher values in the infra-red of the spectrum the probability of attaining any considerable luminous efficiency is ruled out. Zirconia is similarly of no promise because of its low temperature, although, because of its relatively higher visible emissive power, it makes a better showing as a light-producer than do the others of nearly the same temperature.

FIG. 15.



Oxides of low general emissive power:
I. Spectral distribution of emission.
II. Spectral distribution of emission (visible region).
III. Spectral distribution of emissive power.

The fact that stands out prominently from this set of data is the striking superiority of Thoria as a mantle structure. From the spectral emissive power curves it appears that as the temperature is raised, so that the long-wave portion from 5μ outward has less effect on the emission, Magnesia should become as good as, or even better than, Thoria, since its emissive power below 5μ averages less than that of Thoria.

Because of the clear superiority of Thoria as a base, the experiments on oxide mixtures were all made on mixtures with it.

(To be continued.)

ON THE DISTRIBUTION OF THE ENERGY STORED IN REINFORCED CONCRETE BEAMS AND COLUMN-SUPPORTED, FLAT-SLAB FLOORS.

BY

HENRY T. EDDY, C.E. Sc.D., Ph.D., LL.D.

Dean and Professor Emeritus, University of Minnesota, Minneapolis, Minn.

1. SINCE the most accurate and complete test data available respecting reinforced concrete beams is found in Technological Paper No. 2, U. S. Bureau of Standards,[1] in which are given details of tests upon 333 of these beams, for convenience of comparison the developments in this paper will deal with beams reinforced and loaded in the same manner as those in this Paper No. 2.

The beams in Paper No. 2 had a span between supports of $l = 12$ ft., a width of $b = 8$ in., a total depth of 11 in., and a depth to the centre of the bottom layer of steel of $d = 10$ in., a total actual length of 13 ft., a uniform reinforcement from end to end, and equal concentrated loads $= \frac{1}{2} W$ placed at each of the one-third points of the span. The reinforcement consisted of half-inch round rods from two to eight in number, of mild steel with an elastic limit between 33,000 and 41,000 lbs., a yield point between 35,000 and 43,000 lbs., and an ultimate strength between 52,000 and 64,000 lbs.

The reader is referred to the paper itself for the numerical results of the tests, except so far as herein quoted, as well as for the details of the construction of the beams.

2. Let M designate the bending moment, I the moment of inertia, R the radius of curvature, k the proportional depth of the neutral axis, and D the deflection at mid span. None of these quantities except D vary in value between the one-third points, and they also have nearly the same values in the end thirds for some distance from the one-third points toward the ends. Especially is this the case with I and k, as may be known from Figs. 22 to 30, inclusive of Paper No. 2, which reveal the fact that the cracking of the concrete by tension extends throughout almost

[1] By Humphrey and Losse, Government Printing Office, Washington, 1912.

the entire length of the beams, except for a short distance near each end, where the bending moment is so small that the variations in the value of I and k by reason of no cracking have a negligible effect.

Let $A = pbd$ be the cross section of the reinforcing steel in square inches, when p = the steel ratio. Let kd = the depth of the neutral axis below the top of the beam and $i = 1 - k$; also let jd = the depth of the centre of action of the steel below the centre of compression of the concrete. In Paper No. 2, the parabolic law of compression is assumed, *i.e.*, $j = 1 - \frac{3}{8} k$, whereas for straight line compression $j = 1 - \frac{1}{3}k$.

If we assume that the concrete is so cracked that the steel supplies the only tensile resistance, we have from the fundamental equation of flexure, $EI/R = M$, in which the applied bending moment $M = \frac{1}{6} Wl$ throughout the middle third of the span,

Hence,

$$EI = \tfrac{1}{6} Wl R \quad \ldots\ldots (1)$$

But by the similar triangles of the distortion of bending

$$e_s : id :: 1 : R, \text{ or } R = id/e_s = Eid/f_s \quad \ldots\ldots (2)$$

in which $e_s = f_s/E$ is the unit elongation of the steel, E its modulus of elasticity, and f_s the unit stress.

Hence,

$$EI = MR = \frac{id}{6e_s} Wl \quad \ldots\ldots (3)$$

By the usual methods of finding the deflection of beams from their curves of flexure we find the value of the deflection D' at a one-third point of the span from the expression

$$EID' = \frac{Wl^3}{432} \quad \ldots\ldots (4)$$

and for the total deflection D at mid span

$$EID = \frac{23\ Wl^3}{1296} \quad \ldots\ldots (5)$$

Hence,

$$D - D' = 0.87D \quad \ldots\ldots (6)$$

or each one-third point moves downward in bending 87 per cent of the total deflection D at mid span.

Now substitute the value of EI given in (3) in (5) and we have

$$D = \frac{23\ l^2 e_s}{216\ id} \quad \ldots\ldots (7)$$

in which it is tacitly assumed that the mean value of I used in integration in finding the beam deflection in (5) does not differ from the value of I in the middle third as used in (3) by more than a negligible amount. This assumption has been verified as practically admissible by a more complete analysis based on the exact and somewhat larger values of I that occur near the ends of the beams due to concrete and steel acting together, with the resulting larger values of k. It is found that the effect of this upon the ratio 0.87 in (6) may be safely neglected, since although $D-D'$ and D may be changed by small amounts their ratio will be affected by only an inappreciable amount.

Now the work performed by the load and expended upon the beam in the process of gradually loading it is expressed as follows:

$$U = \tfrac{1}{2}W(D - D') = 0.435WD \quad \ldots\ldots (8)$$

in which $D-D'$ is the vertical distance moved through by the load in performing its work. Consequently by (7)

$$U = \frac{10\,W\,l^2 e_s}{216\,id} \quad \ldots\ldots (9)$$

Again, the work stored in the steel of the middle third of the span may be written

$$U_s = \tfrac{1}{6}\,A l f_s e_s \quad \ldots\ldots (10)$$

in which $\frac{1}{3}Al$ is the volume of the steel and e_s its unit elongation. But since the moment of resistance of the steel is equal to the moment of the applied forces we have

$$Af_s\,jd = \tfrac{1}{6}\,Wl \quad \ldots\ldots (11)$$

Therefore,

$$U_s = \frac{W l^2 e_s}{36\,jd} \quad \ldots\ldots (12)$$

Hence,

$$\frac{U_s}{U} = \frac{216\,i}{360\,j} = 0.6\frac{i}{j} \quad \ldots\ldots (13)$$

In case we assume for the moment that $k = 0.4$, which is a good average value for the beam tests in Paper No. 2, we have $i = 0.6$ and $j = 1 - \frac{3}{8}\,k = 0.85$. Then $U_s/U = 0.4235$ is the fraction of the total work of the load which is stored in the steel in the middle third.

It will be fair to estimate the work stored in the steel in the two end thirds as one-half of this amount, because were the same relation to exist in the end thirds between the applied bending moment and the resistance of the steel as in the middle third, then the energy stored in the steel in each end third, and due to a moment uniformly decreasing to the end, would be one-third that in the middle third. But, owing to the existence of tensile resistance in the concrete near the ends, the stresses on the steel are thereby reduced somewhat below one-third, and the amount of work expended upon the steel in each end third may reasonably be taken as reduced to not more than one-fourth that in the middle third or possibly to even less than that, thus giving as an estimated ratio of the total work stored in the steel of the entire span to the work of the load the quantity.

$$\frac{3}{2}\frac{U_s}{U} = 0.9\frac{i}{j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

or in case $k = 0.4$, we have

$$\frac{3}{2}\frac{U_s}{U} = 0.635$$

This is considerably more than one-half of the total work of the load, being some five-eighths of it.

3. The work U_c expended in compressing the concrete of the middle third and stored in it during loading may be calculated in like manner. For on the assumption that beam sections originally plane remain plane after flexure we have

$$\frac{id}{e_s} = \frac{kd}{e_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Hence by (7)

$$D = \frac{23}{216}\frac{f^2 e_c}{kd} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

But U_c is half the product of the total amount of the reduction of length of the concrete at the centre of application of the compressive force multiplied by the total compressive force, *i.e.*, in case of parabolic compression.

$$U_c = \frac{1}{2} \times \frac{1}{3} l \frac{5}{8} e_c \times \frac{2}{3} f_c bkd = \frac{5}{72} lbkdf e_c \quad \ldots\ldots (17)$$

in which $\frac{5}{8}e_c$ is the unit compression at the centre of gravity of

the parabolic area, and the factor following is the total compressive force above the neutral axis.

But since the resisting and the applied moments are equal,

$$\frac{2}{3} f_c\, bkdjd = \frac{1}{6} Wl, \text{ or } bkdf_c = \frac{Wl}{4jd} \quad \ldots\ldots\ldots\ldots (18)$$

Hence,

$$U_c = \frac{5}{228}\frac{W^2 e_c}{jd} = 0.022\,\frac{W^2 e_c}{jd} \quad \ldots\ldots\ldots\ldots\ldots (19)$$

Now using (8), (16) and (19) we have

$$\frac{U_c}{U} = 0.475\,\frac{k}{j}, \text{ or } \frac{3}{2}\frac{U_c}{U} = 0.712\,\frac{k}{j} \quad \ldots\ldots\ldots (20)$$

In case we use $k = 0.4$ we have for parabolic compression, $U_c/U = 0.223$ as the fraction of the work stored in the concrete in the middle third. If this be increased by 50 per cent for the two end thirds we have

$$\frac{3}{2}\frac{U_c}{U} = 0.335 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

for the total compression in the concrete. This last estimate in (21) may be rather excessive as appears when we take the sum of (14) and (21), making a total of

$$\frac{3}{2}\frac{(U_s + U_c)}{U} = 0.97 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

since it would seem probable that more than 3 per cent might be lost in cracking of concrete and slipping of rods in concrete. For this case we have

$$\frac{U_s}{U_c} = 1.226\frac{i}{k} = 1.9$$

However, (21) is somewhat modified in case we assume straight line compression, when we compute instead of (17):

$$U_c = \frac{1}{2} \times \frac{1}{3}\, l \times \frac{2}{3}\, e_c \times \frac{1}{2} f_c bkd = \frac{lbkdf_c e_c}{18} \quad \ldots\ldots (23)$$

But by equating the resisting and applied moments we have

$$\tfrac{1}{3} f_c bkdjd = \tfrac{1}{6} Wl, \text{ or } b\,k\,d\,f_c = \frac{Wl}{3jd}$$

Hence,

$$U_c = \frac{W^2 e_c}{54\,jd} = 0.0185\,\frac{W^2 e_c}{jd} \quad \ldots\ldots\ldots\ldots\ldots (24)$$

and

$$\frac{U_c}{U} = 0.4\,\frac{k}{} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

Now if $k = 0.4$, and $j = 1 - \frac{1}{3} k = 0.87$ we find $U_c/U = 0.184$, and $\frac{U_s}{U} = 0.414$, and $\frac{3}{2} \frac{U_s + U_c}{U} = 0.897$, a not improbable value.

For this case we have

$$\frac{U_s}{U_c} = 1.5 \frac{j}{k} = 2.25$$

The correct values seem probably to lie between those calculated from the hypothesis of parabolic compression and those calculated from the straight line hypothesis. The results thus arrived at indicate that 60 per cent or more of the work expended upon the beam during flexure by the downward movement of the load is stored as potential energy of elastic elongation in the steel, and that approximately half as much has been expended in the longitudinal compression of the concrete.

These results are confirmed by the results of calculations detailed in the accompanying tables, which are based on the average values of k obtained in the tests of beams of seven different steel ratios, as given in Table 26, page 60, of Paper No. 2.

Average Work in Reinforced Concrete Beams as Per Tests in Table 26, Page 60 U. S. Technological Paper No. 2.

No. of ½ inch rods	k, mean of 3 beams	$j = 1 - \frac{3}{8} k$	$\frac{3}{2} \frac{U_s}{U} = 0.9 \frac{j}{j}$	$\frac{3}{2} \frac{U_c}{U} = 0.7 \frac{k}{j}$	$\frac{3}{2} \frac{(U_s + U_c)}{U}$	$\frac{U_s}{U_c}$	$j = 1 - \frac{1}{3} k$	$\frac{3}{2} \frac{U_s}{U} = 0.9 \frac{j}{j}$	$\frac{3}{2} \frac{U_c}{U} = 0.7 \frac{k}{j}$	$\frac{3}{2} \frac{(U_s + U_c)}{2U}$	$\frac{U_s}{U_c}$
$f_s = 16{,}000$ ↑											
2	.358	.866	.667	.294	.961	2.27	.881	.656	.290	.946	2.26
3	.380	.8575	.651	.309	.960	2.16	.873	.639	.311	.950	2.05
4	.418	.843	.621	.351	.972	1.77	.861	.608	.345	.953	1.76
5	.407	.847	.630	.342	.972	1.84	.864	.618	.335	.953	1.85
6	.428	.840	.615	.363	.978	1.69	.857	.600	.356	.956	1.68
7	.443	.834	.602	.378	.979	1.59	.852	.587	.371	.958	1.58
8	.455	.829	.591	.382	.982	1.51	.848	.578	.383	.961	1.51
Mean ↓	.413	.845	.625	.360	.975	1.81	.862	.614	.341	.955	1.81
$f_s = 32{,}000$ ↑											
2	.288	.892	.719	.230	.949	3.13	.908	.705	.225	.930	3.13
3	.325	.878	.692	.261	.953	2.65	.892	.681	.258	.939	2.64
4	.360	.835	.690	.306	.996	2.25	.880	.654	.291	.945	2.25
5	.359	.865	.666	.296	.962	2.25	.880	.656	.290	.946	2.26
6	.381	.857	.650	.317	.967	2.05	.873	.638	.311	.948	2.05
7	.402	.842	.641	.339	.980	1.90	.866	.621	.330	.951	1.88
8	.416	.844	.623	.351	.954	1.77	.861	.611	.345	.956	1.77
Mean	.361	.859	.669	.300	.969	2.29	.880	.652	.293	.945	2.22

4. In order to determine what part of the total work done by the load on a flat-slab floor is expended upon and stored in the slab steel reinforcement, assume that the centre of gravity of a uniformly distributed panel load W moves downward during loading through a distance equal to one-half of the total deflection D_2 of the panel centre. This estimate of a mean deflection $= \frac{1}{2}D_2$ probably exceeds the actual amount of the mean downward motion by a very small amount in case of many panels equally loaded, but is probably somewhat too small for the case of a single-loaded panel, especially for a deck slab, or one supported on columns of small stiffness, for, under such conditions the lines of inflection approach nearer to the supports, and the dish-shaped or suspended spans around the panel centres are somewhat larger in area than when all panels are loaded. This assumed value of $\frac{1}{2}D_2$ is, however, sufficiently accurate to enable us to make a satisfactory comparison of work done in slabs with that already found for beams.

The expression for the work of a load gradually applied to a panel is one-half the product of the load W, by the mean deflection $\frac{1}{2}D_2$ *i.e.*,

$$U = \tfrac{1}{4} WD_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

in which D_2 may be obtained by test, or usually with sufficient accuracy from equation (71) page 204, "Concrete Steel Construction," Eddy and Turner. Now making use of this value of D_2 first before we have recourse to experimental confirmation

$$U = \frac{W^2 l^3}{19 \times 10^{10} A_1 d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

in which l is the span in inches, A_1 the cross section of a single belt, in case of four-way reinforcement of side and diagonal belts, and d is the depth of the centre of gravity of the steel below the top of the slab at the panel centre.

Again, U_2 the work stored in the slab rods of a panel is equal to one-half the product of the volume of steel in the rods, multiplied by the mean value of the product of unit stress f and unit strain e, *i.e.*, by the mean value of $f_e = f^2/E$. Now the volume of steel in the side and diagonal belts of a square panel is

$$v = 2\,(1 + \sqrt{2})\, lA_1 = 4.83\, lA_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

and the mean value of f^2 in a rod is $\frac{1}{3} f_s^2$ when f_s is the maximum steel stress at mid span, provided the stress diminishes uniformly to zero at the lines of inflection. Although it does not diminish at so rapid a rate as this near its maximum value, nevertheless $\frac{1}{3} f_s^2$ is a suitable value to assume because not all the rods in a belt have stresses at mid span as large as the largest observed in either rod.

Let us assume from Equation (34), page 183, and from equation (52), page 196, "Concrete Steel Construction," that a mean maximum value at mid span is

$$f_s = \frac{Wl}{200\, A_1 d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

Then the work stored in the slab rods of a panel is

$$U_2 = \tfrac{1}{2} v \times \tfrac{1}{2} \frac{f_s^2}{E} = \frac{4.83\, l A_1}{6 \times 3 \times 10^7} \left(\frac{W l}{200\, d\, A_1}\right)^2 \ldots\ldots (30)$$

Hence by (26) and (30)

$$\frac{U_2}{U} = 0.127 = \tfrac{1}{8} \text{ nearly} \quad \ldots\ldots\ldots\ldots\ldots\ldots (31)$$

By (26), (28) and (30) this ratio may also be found otherwise in terms of observed quantities, without assuming (29) as follows:

$$\frac{U_2}{U} = \frac{1.07\ 1\ A_1 f_s}{10^7\, W\, D_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (32)$$

which may therefore be used to calculate the proportion of the total work of deflection stored in the steel from test data alone and independently of theory, since it depends on observed quantities only.

For example, in the test of the Deere and Webber Building* assuming a mean observed value of $f_s = 9000$ at mid span

$$\frac{U_2}{U} = \frac{1.07 \times 226 \times 12 \times 0.15\ (9\,000)^2}{107 \times 124\,678 \times 0.224} = 0.126$$

Similarly in the test of the Northwestern Glass Company Building† $U_2/U = 0.121$, and in the St. Paul Bread Company Building‡ $U_2/U = 0.128$. These results of tests differ very little from the theoretical value obtained above in (31). They show con-

* See "Concrete-Steel Construction," page 228.
† Page. 227.
‡ Page 232.

clusively that a much smaller proportion of the total work of the load is stored in the reinforcing rods of a slab than in those of a beam, in fact under test conditions only about one-fifth as much.

This difference is so large as to make it certain that beam theory is entirely inapplicable to flat slabs, as it evidently should be when we consider the physical and mechanical dissimilarity of the two structures, one of the most noticeable of which is the almost total loss of resistance of concrete in the tensile regions of beams under heavy load, as shown by the numerous cracks below the neutral axis already referred to, while ordinary tests of slabs show little if any cracking that would materially reduce the resistance of the concrete in opposing the very complicated stresses to which the concrete is subjected in the tensile zones of the panel, to all of which the concrete opposes an effective resistance, as is evident from the fact that it continues intact. The dissemination of the steel in a fine-grained structure throughout these zones enables it to bring all the concrete into action in such a way as to afford the resistance needed to effect a result such as is impossible in beams, since in the tensile zones of slabs it is subjected to a combination of several compressions, twists and shears, which it is abundantly able to bear; and it must be remembered, in this connection, that any kind of resistance called into play in such a structure assists by just so much in transmitting the load to the supports. The concrete in a slab, without being taxed beyond its direct tensile resistance, as it is taxed in beams, is able to afford at the same time other effective resistances that relieve the steel and greatly enhance the load carrying capacity of the slab.

If only about $\frac{1}{8}U$ is stored in the slab steel, where, it may be asked, is the remaining $\frac{7}{8}U$ to be found? Most of it must be found somewhere in the concrete, which is subjected to various kinds of stress not found in beams. In fact, the numerous observable and microscopic cracks in beams almost entirely prevent any storage of energy in the concrete, except that of compression, and a small amount in vertical and horizontal shear, while the almost total absence of cracks in slabs permits the storage of more energy in shears than in beams, and permits the storage of energy in the slab in twisting and in several other ways, as well as in bond shear deformations throughout the tensile zones of the slab.

The enormous difference which we have found above between the storage of energy in beams and slabs thus proves conclusively that the mode of action of slabs is entirely different from that of beams, and that their analysis must also be entirely different. It is consequently wholly inadmissible to attempt to compute slabs by beam theory.

5. *Summary.*—Uniformly reinforced concrete beams loaded at the one-third points store some 60 per cent. or more of the total energy of flexure in the steel reinforcement alone, and only about half as much in longitudinal compression in the concrete.

Uniformly loaded flat slab floors with four-way reinforcement store only about 12.5 per cent. of the total energy of flexure in the slab steel. Since this is only about one-fifth of the amount stored in beams, it evidently is impossible to compute slabs by beam theory.

Asbestos Production. J. S. DILLER. (*U. S. Geological Survey.*)—The asbestos industry of the United States is in better condition now than ever before, especially as to the quantity and the grade produced, and the outlook is encouraging. Most of the asbestos used in the large asbestos factories of the United States comes from Canada, but the growing appreciation of the high quality American fibre, especially that from Arizona, is a welcome feature of the industry.

The total quantity of domestic asbestos sold in 1917 was 1683 short tons, valued at $506,056, an increase of about 13 per cent. in both quantity and value over 1916. Most of the domestic asbestos comes from Arizona, where the proportion of crude spinning fibre to that of lower grades is much larger than in Canada, so that the average price of American fibre in 1917 was $301 a ton, whereas the average price of that in Canada was only about $50.

Some years ago the opinion was expressed that as the Arizona fibre contains less iron than that mined in Canada it is therefore better adapted to use for electrical insulation than the Canadian fibre.

A small amount of spinning fibre was mined in Fremont County, Wyo., from a contact deposit of remarkable interest.

The increased demands for asbestos due to the war have been met largely by increased imports from Canada. The imports of asbestos from South Africa and Italy have been largely cut off. The demand for imported asbestos for use in filters is being supplied by amphibole asbestos obtained from residual deposits of the crystalline rocks of Maryland.

SOIL ALDEHYDES.*

A Scientific Study of a New Class of Soil Constituents Unfavorable to Crops, Their Occurrence, Properties and Elimination in Practical Agriculture.

BY

JOSHUA J. SKINNER, Ph.D.

The heliotropine affected the plants markedly from the beginning. The concentration used proved very harmful, and the plants in the entire set of solution made only a small growth. Both tops and roots were injured. The tops, however, seemed more affected than the roots.

The green weights of each set of cultures are given in the diagrams of Fig. 23.

An examination of the two diagrams shows the green weight of each culture in the heliotropine set to be much smaller than the corresponding culture in the set without heliotropine. The total weight of all the cultures in the normal set was 185.4 grammes, and that of the heliotropine set 69.3 grammes. This is a reduction of 62 per cent. in growth. The 21 solutions in the phosphate end of the triangle produced 50.3 grammes green weight in the set without heliotropine and only 17.5 grammes in the set with heliotropine, a reduction of 65 per cent. The 21 cultures in the nitrate end of the triangle produced 52.7 grammes green weight in the normal set and 23.0 grammes in the heliotropine set, a reduction of 61 per cent., and the same number of cultures at the potash end of the triangle produced 54.4 grammes green weight in the normal cultures and 25 grammes in the treated set, which is a reduction of 54 per cent. This indicates that heliotropine may be less harmful in solutions containing high proportions of potassium. The injury to the plants over the entire triangle was so great, however, that conclusions should not be drawn. The absorption of salts by the plants is not in harmony with the more normal growth in the high potash solution.

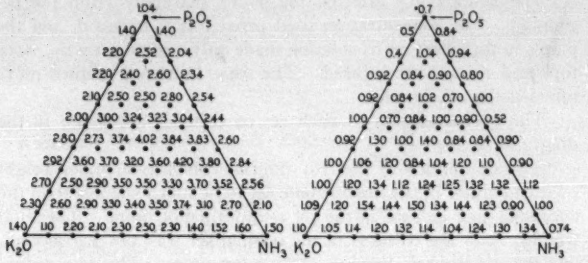
* Continued from page 316, Vol. 186, September, 1918.

Absorption of Nutrient Salts.

The total absorption of P_2O_5, nitrates stated as NH_2, and K_2O for all the cultures of the normal triangle was 1726.7 milligrammes and only 668.0 milligrammes for the cultures of the heliotropine set.

Phosphates.—The plants in the normal set absorbed 446.3 milligrammes of P_2O_5, while the plants of the heliotropine set absorbed 163.0 milligrammes, 283.3 milligrammes less, a reduction of 64 per cent.

FIG. 23.



Green weight in grammes of wheat plants in nutrient solutions containing varying ratios of phosphate, nitrate and potash: (1) Without heliotropine and (2) with 25 ppm. heliotropine.

Nitrates.—The normal cultures absorbed 620.1 milligrammes of nitrates stated as NH_3, and the heliotropine cultures 277.4 milligrammes, 342.7 milligrammes less, or a reduction of 56 per cent.

Potash.—The absorption of potash was 660.2 milligrammes of K_2O by the normal cultures and 227.6 milligrammes by the heliotropine cultures, 432.6 milligrammes less. This is a reduction of 66 per cent.

The nitrate absorption seems to have been the least interfered with by the presence of heliotropine, yet the plants made a more normal growth in the high potash solutions. The absorption of each of the nutrient salts was greatly interfered with, as well as the growth of the plants.

FORMALDEHYDE.

Formaldehyde, HCOH, is a powerful disinfectant, either as a gas or in solution. It is formed from methyl alcohol by oxidation. The action of formaldehyde in plants is interesting on account of the well-known assumption of Beyer's (5); namely, the production of formaldehyde in plants through the interaction of carbon dioxide and water, and the subsequent polymerization of this to a sugar. It was also suggested by Erlenmeyer (17) that carbonic acid is acted on by water under conditions existing in the plant with the production of formic acid and hydrogen peroxide. The formaldehyde would then result from the reduction of formic acid. Numerous investigations attempting the formation of formaldehyde directly from carbonic acid and water have been reported. Lob (28) claims its formation by substituting sunlight by a silent electric discharge, and in this way it shows that formaldehyde is a direct reduction product of CO_2 and H_2O, and Fenton (19) claims to have accomplished its formation directly from carbonic acid by passing a current of carbon dioxide through pure water in contact with several rods of amalgamated magnesium.

As a result of Beyer's hypothesis attempts have been made to detect formaldehyde in plants of various species and grown under various conditions. This has been difficult, for if formaldehyde exists in plants it can be present only in minute quantities on account of its great toxicity. Usher and Priestley (77) claim to have definitely proved its presence in dead plants. Most investigators assume its presence in living plants, but are unable to demonstrate this on account of lack of sensitiveness of methods to detect such minute quantities as must exist in plants. Angelico and Catalano (1), by means of the active glucoside principle of *Atractylis gummifora*, detected formaldehyde in the juices of green plants of many species.

Effect on Growth.

A great many experiments have been made on the assimilation of formaldehyde by plants. The first extensive investigation was made by Bokorny (6), who attempted to grow water plants in diluted solutions. In concentration of 20 parts per million the plants were killed. Methylal, which decomposes into formaldehyde, giving up extremely small amounts, stimulated the growth

of *Spirogyra* and produced starch in the absence of carbon dioxide. It was also shown that water-cress assimilated formaldehyde vapor in the absence of both oxygen and light (7).

Formaldehyde in air free from carbon dioxide produced a stimulation of *Phaseolus vulgaris*, as shown by Grafe and Vieser (23). Bouilloc and Guistiniana (8) succeeded in growing white mustard in solutions containing traces of formaldehyde; they report a stimulation when the plants were grown in the light. Elodea were grown successfully in solutions containing 10 parts per million of formaldehyde (9). Baker (3), who also studied the effect of formaldehyde vapor on the growth of white mustard, found that the plants could use the aldehyde for synthesis of food material to some extent in the light. There was considerable gain in dry weight of the plant under the influence of the aldehyde. The poisonous effect with the higher concentrations was more intense in darkness than in light. Among other experiments recorded, Clark (15) reports that formaldehyde is very toxic to fungi, being fatal to several species in $\frac{N}{2048}$ solutions. A distinct injury was exhibited in $\frac{N}{4096}$ solutions, but all the fungi tested produced normal development in a $\frac{N}{131072}$ solution. No stimulation is reported.

Effect in Nutrient Solutions with Various Fertilizer Salts.

In the experiments recorded in this paper with formaldehyde in nutrient solutions the complete triangular set was used. The formaldehyde was used in concentrations of 20 parts per million. Wheat plants grew in these solutions from March 31 to April 12, 1915. As in the former experiments with the other aldehydes, four changes of solutions were made. The solutions were analyzed to determine the amount of nutrients absorbed.

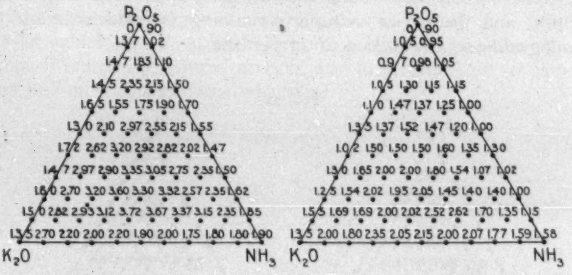
The green weight of the wheat plants of each solution without and with formaldehyde are given in diagrams of Fig. 24.

The results of the experiment are in harmony with those of former investigations. The aldehyde reduced growth very much. In most of the cultures the green weight is less in the formaldehyde solution than in the corresponding culture without formaldehyde. The total green weight of all the cultures of the normal set was 149.8 grammes, against 104.3 grammes for all the cultures

in the formaldehyde set. The formaldehyde at the concentration used reduced growth 30 per cent.

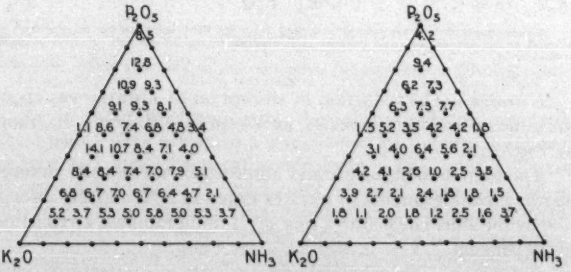
When the cultures are considered from the point of view of the composition of the solution, it is seen there were practically no

FIG. 24.



Green weight in grammes of wheat plants in nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without formaldehyde and (2) with 20 ppm. formaldehyde.

FIG. 25.



Milligrammes of P_2O_5 absorbed from nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without formaldehyde and (2) with 20 ppm. formaldehyde.

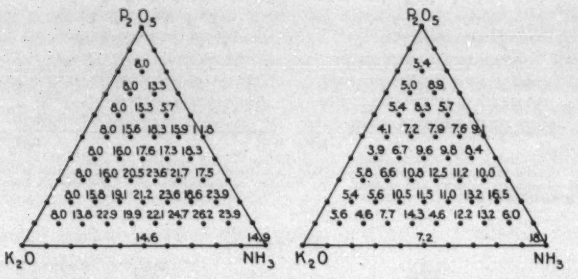
differences in the harmfulness of formaldehyde in the different sections of the triangle. In the mainly phosphatic cultures growth was reduced 32 per cent., in the mainly nitrogenous 30 per cent., and in the mainly potassic 31 per cent.

Absorption of Nutrient Salts.

Phosphates.—The absorption of all salts was also much less in the cultures with formaldehyde. The amounts of P_2O_5 removed by the plants in each culture are given in diagrams of Fig. 25.

The normal set of cultures absorbed 265.0 milligrammes of P_2O_5, and the set of cultures containing formaldehyde 140.3 milligrammes, a reduction of 47 per cent.

FIG. 26.



Milligrammes of NH_3 as nitrate absorbed from nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without formaldehyde and (2) with 20 ppm. formaldehyde.

Nitrates.—The reduction in absorption of nitrates was about the same as that of phosphates, as is seen by examining diagrams of Fig. 26.

The total amount of nitrates absorbed by the normal cultures was 621.6 milligrammes of nitrates stated as NH, and the absorption by the aldehyde cultures was 337.1 milligrammes, a reduction of 46 per cent.

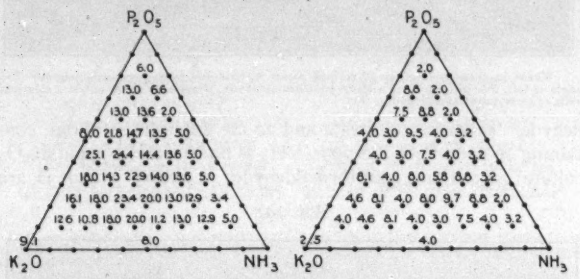
Potassium.—The absorption of potash was interfered with more by the presence of formaldehyde than were phosphates or nitrates. The total amount of K_2O removed by the normal cultures was 415.4 milligrammes, against 204.5 milligrammes for the set of cultures containing formaldehyde. This is a reduction of 60 per cent. The detail figures are given in diagrams of Fig. 27.

PARAFORMALDEHYDE.

Effect in Solutions with Various Fertilizer Ingredients.

Paraformaldehyde, $\begin{matrix}HCOH\\HCOH\end{matrix}$, is a polymeric variety of formaldehyde. It is a solid substance, and is formed when a water solution of formaldehyde is evaporated. So far as the author is aware, its effects on plant growth had not before been determined. In the experiments reported below it proved to be fully as harmful as formaldehyde. In 25 parts per million in nutrient-culture solutions it materially injured growth, and in solutions of 50 parts per million it was extremely harmful.

FIG. 27.



Milligrammes of K_2O absorbed from nutrient solutions containing varying ratios of phosphate nitrate, and potash: (1) Without formaldehyde and (2) with 20 ppm. formaldehyde.

As in the experiments with the other aldehydes reported, wheat plants were grown in a complete set of nutrient solutions, without and with the paraformaldehyde. The solutions were prepared according to the triangular schemes, there being 66 in each set. The plants grew from January 27 to February 8, 1917. The solutions were changed four times during the experiment. The paraformaldehyde was used in this test in amounts of 25 parts per million. Photographs were taken when the plants were ten days old. In Fig. 28 the two sets of cultures are shown in triangular form. The triangle on the left is the normal solutions—that is, the set without paraformaldehyde—and the triangle on the right is the set containing 25 parts per million paraformaldehyde. The difference in growth as shown in the plate between the two sets of plants is very marked. A near view of

three of the cultures is shown in Fig. 29. Cultures 1 and 1*a* are duplicate solutions, containing 48 ppm. P_2O_5, 16 ppm. NH_3 as nitrate, and 10 ppm. K_2O. Culture 1*a* contains the paraformal-

FIG. 28.

Wheat in nutrient solutions of various ratios without and with paraformaldehyde: Triangle on left, nutrient solutions without paraformaldehyde; triangle on right, nutrient solutions with 25 ppm. paraformaldehyde.

dehyde. Likewise cultures 2 and 2*a* are duplicate solutions, containing 16 ppm. P_2O_5, 48 ppm. NH_3 as nitrate, and 16 ppm. K_2O; culture 2*a* contains paraformaldehyde. Cultures 3 and 3*a* are

FIG. 29.

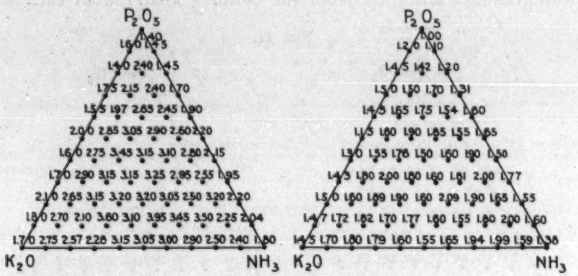
Nutrient solutions without and with paraformaldehyde: No. 1 and 1*a*, solution containing 48 ppm. P_2O_5, 16 ppm. NH_3, and 10 ppm. K_2O.; No. 2 and 2*a*, containing 16 ppm. P_2O_5, 48 ppm. NH_3, and 16 ppm. K_2O.; No. 3 and 3*a*, solution containing 16 ppm. P_2O_5, 16 ppm. NH_3, and 48 ppm. K_2O. Bottles marked "a" contain 25 ppm. paraformaldehyde.

also duplicates, containing 16 ppm. P_2O_5, 16 ppm. NH_3 as nitrate, and 48 parts per million K_2O. Culture 3*a* contains the paraformaldehyde. Here it is seen that the aldehyde had affected root

growth as well as top growth in each of the solutions, regardless of its composition. In the diagrams of Fig. 30 are given the green weights of the plants in the normal set of solutions and in the paraformaldehyde set.

The growth in each solution containing paraformaldehyde is smaller than in the corresponding solution without it. The total growth of the 66 normal cultures was 165.7 grammes, and that of the paraformaldehyde set 107.2 grammes. This is a reduction of 35 per cent. in growth.

FIG. 30.



Green weight in grammes of wheat plants in nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without paraformaldehyde and (2) with 25 ppm. paraformaldehyde.

When the cultures are considered from the point of view of their composition, it is seen that growth was more normal in solutions in the phosphate end of the triangle. Referring again to Fig. 5, the cultures in sub-triangle 1–16–21—that is, the 21 mainly phosphatic solutions—produced 43.8 grammes green matter in the normal set and 31.1 grammes in the paraformaldehyde set, a reduction of 30 per cent. The 21 mainly nitrogenous cultures (sub-triangle 21–61–66) produced 55.9 grammes green matter in the normal set and 36.3 grammes in the aldehyde set, a reduction of 35 per cent. The 21 mainly potassic solutions (sub-triangle 16–56–16) produced 54.0 grammes and the aldehyde solutions 34.5 grammes, a reduction of 37 per cent.

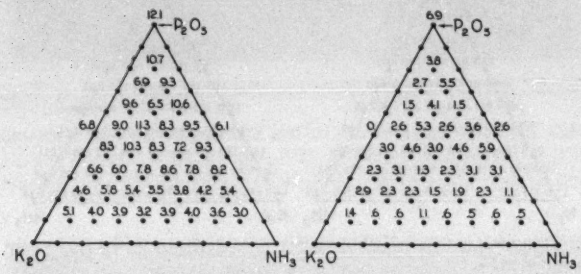
Another experiment using the complete set of nutrient solution without and with paraformaldehyde was made in which the aldehyde was used in amounts of 50 parts per million. This proved very harmful to the plants. Growth was reduced 58

per cent. as an average of the entire set. In this experiment growth was also more normal in the mainly phosphatic cultures. So the results as to its relative harmfulness in nutrient solutions of different compositions do not seem merely accidental. It is rather markedly indicated that phosphates ameliorate its harmful effect.

Absorption of Nutrient Salts.

Phosphates.—The absorption of salts was greatly decreased by the action of paraformaldehyde. The amount of P_2O_5 in milligrammes absorbed from the cultures analyzed in each set

FIG. 31.



Milligrammes of P_2O_5 absorbed from nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without paraformaldehyde and (2) with 25 ppm. paraformaldehyde.

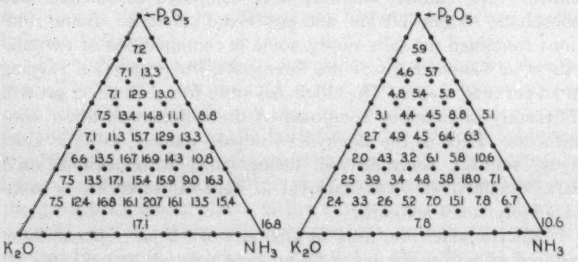
are given in the diagrams of Fig. 31. The normal set of cultures absorbed 270.8 milligrammes and the paraformaldehyde set only 99.4 milligrammes. The absorption of P_2O_5 was reduced 63 per cent.

Nitrates.—The absorption of nitrates was not lessened quite so much as were the phosphates. The amount absorbed from each solution can be seen by examining the diagrams of Fig. 32. The normal set of cultures removed from the solutions 602.8 milligrammes of NH_3 as nitrates, and the paraformaldehyde set only 238.0 milligrammes. This is a reduction of 63 per cent. in the amount of nitrate absorbed.

Potash.—The decrease in the amount of K_2O removed was even greater than the phosphates or nitrates. The detail figures showing the removal of K_2O from each set of solutions are given

in diagrams of Fig. 33. The total amount of K_2O in milligrammes removed from the solutions in the normal set was 531.8 and from the aldehyde set 177.8, a reduction of 67 per cent.

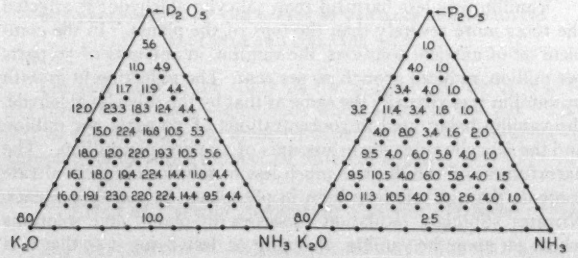
FIG. 32.



Milligrammes of NH_3 as nitrate absorbed from nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without paraformaldehyde and (2) with 25 ppm. paraformaldehyde.

Although growth was more normal in the mainly phosphatic solutions, showing that there was some action by the phosphates which changed the physiological effect of paraformaldehyde, the

FIG. 33.



Milligrammes of K_2O absorbed from nutrient solutions containing varying ratios of phosphate, nitrate, and potash: (1) Without paraformaldehyde and (2) with 25 ppm. paraformaldehyde.

absorption of nitrates by plants growing in the presence of this aldehyde was more normal than the absorption of phosphates or of potash.

SUMMARY OF THE EXPERIMENTS ON THE EFFECT OF ALDEHYDES ON GROWTH IN CULTURE SOLUTIONS.

The effects of six different aldehydes on the growth of plants in distilled water and in nutrient culture solutions were determined. The culture solutions were composed of calcium acid phosphate, sodium nitrate, and potassium sulphate. Some solutions contained the salts singly, some in combinations of two and others in combinations of the three salts, the proportion varying in 10 per cent. stages. The aldehydes were found to affect growth differently in solutions composed of the different fertilizer constituents. Each of the aldehydes studied—namely, salicylic aldehyde, vanillin, benzaldehyde, heliotropine, formaldehyde, and paraformaldehyde—was harmful in aqueous solutions in comparatively small amounts.

Salicylic aldehyde, used in amounts of 10 parts per million, reduced growth in the set of 66 nutrient solution 27 per cent. It was least harmful in those solutions containing a high percentage of phosphate, and its harmfulness was somewhat lessened in the solutions in the presence of calcium carbonate. There was a more nearly normal absorption of phosphate than of nitrates or potash under the influence of salicylic aldehyde. This is in harmony with the relatively lessened toxicity of the aldehyde in the mainly phosphatic nutrient solutions.

Vanillin was less harmful than salicylic aldehyde; it affected the roots more severely than the tops of the plants. In the complete set of nutrient solutions, the vanillin, in amounts of 50 parts per million, reduced growth 26 per cent. The reduction in growth by vanillin was virtually the same as that by the salicylic aldehyde, the vanillin being used in concentrations of 50 parts per million and the salicylic aldehyde in amounts of 10 parts per million. The harmfulness of vanillin was much less in solutions high in nitrate contents than in solutions high in phosphate or potash contents. Nitrates stimulate oxidation processes in plants and solutions which act upon the vanillin, changing or destroying it so that it is no longer harmful to plants.

Benzaldehyde, in concentrations of 25 parts per million, in the total number of nutrient solutions used in the experiment, reduced growth 30 per cent. Growth in the benzaldehyde solutions was slightly more normal in the phosphatic and potassic than in the nitrogenous solutions, and the absorption of potash was

slightly more normal than the absorption of either phosphates or nitrates.

Heliotropine proved to be extremely harmful in concentrations of 25 parts per million, reducing growth 62 per cent. as an average of all the cultures. The plants were so severely injured that it was difficult to differentiate between its effects in the different solutions.

The well-known effects of formaldehyde were again demonstrated. Growth was reduced in the nutrient solution 30 per cent. when the aldehyde was used in concentrations of 20 parts per million. It was equally harmful in the different solutions, regardless of their compositions in nutrient salts. Paraformaldehyde also proved to be harmful; in 25 parts per million it reduced the growth of wheat plants in the various nutrient solutions 35 per cent., and in concentrations of 50 parts per million it severely injured the plants. It was less harmful in the solutions containing principally phosphates. It is markedly indicated that phosphates have an ameliorating action on its effect.

In the following sections the results of pot and field studies are presented. In these experiments only salicylic aldehyde and vanillin, the two aldehydes which have been encountered frequently in soils, were used.

POT EXPERIMENTS ON THE EFFECT OF VANILLIN AND SALICYLIC ALDEHYDE IN DIFFERENT SOILS.

The next step in the study of the action of aldehyde was to test the effect of these compounds when added to the soil. This part of the investigation involved experiments with a number of different plants and a number of different soils.

Effect of Varying Amounts of Salicylic Aldehyde.

The first experiment with salicylic aldehyde was with a heavy clay soil and wheat was grown. Paraffin pots (22) holding approximately one pound of soil were used, and six plants were grown in each pot. Before potting, portions of the soil were treated with varying amounts of salicylic aldehyde. The experiment was begun May 27 and discontinued June 18. The appearance of the plants near the end of the experiment is shown in

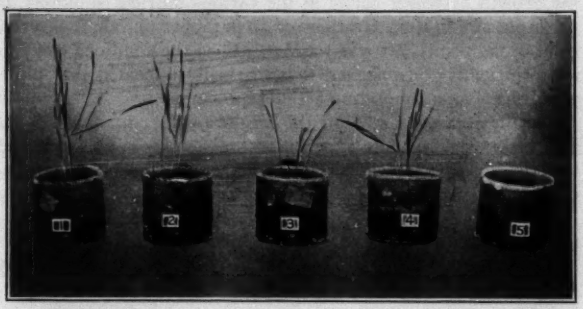
Fig. 34, and here it is clearly seen that the aldehyde is very harmful. The results are given in Table X.

TABLE X.

Effect of Salicylic Aldehyde on Wheat Plants in Soil.

No.	Treatment	Green weights grammes	Relative growth
1	Clay loam untreated	0.65	100
2	Same + 10 ppm. salicylic aldehyde	0.65	100
3	Same + 25 ppm. salicylic aldehyde	0.50	77
4	Same + 50 ppm. salicylic aldehyde	0.40	61
5	Same + 100 ppm. salicylic aldehyde	dead	...
6	Same + 200 ppm. salicylic aldehyde	dead	...

FIG. 34.



Effect of different concentrations of salicylic aldehyde on wheat: No. 1, soil untreated; No. 2 salicylic aldehyde, 10 ppm.; No. 3, 25 ppm.; No. 4, 50 ppm.; No. 5 ,100 ppm.

The weights in the table show that 10 parts per million of salicylic aldehyde in this soil had no effect, while larger amounts were quite harmful. With 25 parts per million, growth was reduced from 100 to 77, or 23 per cent.; with 50 parts per million the growth was reduced from 100 to 61, or 39 per cent. Where 100 and 200 parts per million were used the plants were killed. This experiment gives some idea as to the concentration of salicylic aldehyde that plants can stand in a soil of this kind.

The action of the aldehyde in soil and in sand was tested as to its effect on corn. The aldehyde was added to a clay soil and to a pure quartz sand in amounts of 50 parts per million. It proved very harmful.

The corn in the sand showed more harmful effect than in the clay soil. The plants grew in the small pots for one month. The salicylic aldehyde reduced growth in the clay soil 24 per cent. and in the sand 60 per cent. That the harmfulness was more marked in the sand than in the clay is probably due to the absorptive power of the clay being far greater than that of the sand, and perhaps, also, to the higher nutritive value of the soil in comparison with the pure sand.

An experiment with clover grown in a clay soil in an earthenware pot holding six pounds of soil should also be recorded here. In this test the aldehyde was added periodically during the time of the experiment. The total amount added was 100 parts per million. The clover grew from April 12 to June 21, 1912. The treated pot showed not only a poorer growth, but also a much faded color, and had a decidedly unhealthy appearance. The green weights taken at the termination of the experiment were 8.5 grammes from the control pot and only 4.2 grammes from the salicylic aldehyde-treated pot, a decrease of approximately 50 per cent. From the three experiments recorded above it is shown that salicylic aldehyde is harmful in soil and sand to wheat, corn, and clover in comparatively small amounts.

Effect of Varying Amounts of Vanillin.

Several experiments showing the effect of vanillin in soil in pots were reported in 1915 (68). Vanillin proved harmful in some of these soils, while in others it had no effect. To clover grown in Chester loam soil it was very harmful. The clover was grown in earthenware flower pots holding six pounds of soil. A total of 300 parts per million of vanillin was added to the treated pot.

When the soil was potted and planted April 28, 100 parts per million of vanillin was added, on May 15 another 50 parts per million was added, and on June 1 and 10, 50 parts per million was added. The experiment was discontinued June 21, 1912. The effect of the vanillin was noticeable from the first. The vanillin-treated plants were healthy in appearance but stunted in growth. The untreated and treated pots are shown in Fig. 35. The green weight taken at the termination of the experiment was 8 grammes for the untreated pot and only 3.8 grammes from the vanillin-treated pot, a decrease of 53 per cent.

The soil used in this experiment was a soil of moderate productiveness, and vanillin applied to it at different periods of growth of the plants was distinctly harmful. Other experiments were made to test the effect of different amounts of vanillin in several soils, each having different properties and being of different geological origin. In the following experiments wheat was used as the test crop, and the total application of vanillin was made before the soil was potted and seeds planted.

FIG. 35.

Effect of vanillin on clover: No. 1 untreated; No. 2, vanillin.

The soils used were infertile sand from Florida, an infertile sample of Susquehanna sandy loam, and a good sample of Hagerstown loam. The paraffined wire pot method was used; six wheat plants were grown in each pot, and two pots were used for each treatment. The plants grew from May 5 to May 24. Photographs of the growing plants were taken, which show the action of vanillin in each soil. At the end of the experiment the green weight was determined.

The Florida sand used in this experiment had grown citrus fruits in the field and was unproductive. A laboratory examination showed the soil to be acid. Vanillin was isolated from this

soil in the investigations referred to above. The Susquehanna sandy loam was taken from an infertile area in Maryland. The natural growth on this soil was poor, and its response to fertilizer and cultural treatments was only moderate. Its oxidizing power and life activities were found to be very weak. The Hagerstown loam is a fertile soil. The soil was taken from a productive field of the Pennsylvania Agricultural Experiment Station. The soil is neutral in reaction, has strong oxidizing power, and grows thrifty plants in pots.

Vanillin was used in amounts of 100 to 500 parts per million. It was applied to the soil by dissolving in water and mixing the solution in the soil before potting. The results of the experiment on the effect of vanillin in the Florida sand, Susquehanna sandy loam, and Hagerstown loam are given in Table XI. The actual green weights of the plants grown in the two pots are given for each treatment, and the relative weight with the growth in the untreated soil taken as 100.

TABLE XI.

Effect of Vanillin on Wheat Plants in Pots Grown in Florida Sand, Susquehanna Sandy Loam, and in Hagerstown Loam.

Treatment	Florida yellow sand (infertile sand)		Susquehanna sandy loam (unproductive soil)		Hagerstown loam (productive soil)	
	Green weight	Relative weight	Green weight	Relative weight	Green weight	Relative weight
	Grammes		*Grammes*		*Grammes*	
Soil untreated	1.40	100	1.80	100	1.98	100
Soil + 100 ppm. vanillin	1.32	94	1.85	103	1.87	94
Soil + 200 ppm. vanillin	1.32	94	1.70	94	2.02	102
Soil + 300 ppm. vanillin	1.35	98	1.33	74	2.05	103
Soil + 400 ppm. vanillin	1.20	86	1.30	72	1.96	99
Soil + 500 ppm. vanillin	1.18	84	1.02	57	1.95	99

The vanillin was quite harmful in amounts of 400 and 500 parts per million in the Florida sand, and was only moderately harmful in amounts of 100 to 300 parts per million. With the Susquehanna sandy loam the vanillin reduced growth considerably when applied at the rate of 300, 400, and 500 parts per million. It was slightly harmful with 100 and 200 parts per million. Vanillin had no harmful effect in the Hagerstown loam: two of the treatments were slightly above the check and three

slightly below. The growth in the untreated soil of the Hagerstown loam was better than in the Susquehanna sandy loam and considerably better than in the Florida sand. The effect of vanillin

FIG. 36.

Effect of vanillin on wheat in Florida sand: No. 1, soil untreated; No. 2, vanillin 100 ppm.; No. 3, vanillin 200 ppm.; No. 4, vanillin 300 ppm.; No. 5, vanillin 400 ppm.; No. 6, vanillin 500 ppm.

in the Florida sand is shown in Fig. 36; in the Susquehanna sandy loam in Fig. 37, and in the Hagerstown loam in Fig. 38.

FIG. 37.

Effect of vanillin on wheat in Susquehanna sandy loam: No. 1, soil untreated; No. 2, vanillin 100 ppm.; No. 3, vanillin 200 ppm.; No. 4, vanillin 300 ppm.; No. 5, vanillin 400 ppm.; No. 6, vanillin 500 ppm.

It is seen from this experiment that vanillin is harmful in two of the soils and has no effect in the third. Vanillin is easily oxidized and changed under favorable conditions, and if this took

place the action on plant growth would not be noticeable. The Florida sand was found to contain vanillin when sent in from the field, and, as would be expected, added quantities of vanillin would not be changed and it would remain as such to have its effect on plants grown in the soil. The Susquehanna sandy loam is also a soil having small oxidizing power and low life activity, and added quantities of vanillin apparently remained as such and had their effect on plant growth. The Hagerstown loam is a soil of entirely different characteristics, being highly productive, which indicated good life activities and good oxidizing power. Vanillin, when added, does not have harmful effects on plants grown in the

FIG. 38.

Effect of vanillin on wheat in Hagerstown loam: No. 1, soil untreated; No. 2, vanillin 100 ppm.; No. 3, vanillin 200 ppm.; No. 4, vanillin 300 ppm.; No. 5, vanillin 400 ppm.; No. 6, vanillin 500 ppm.

soil, as it probably does not remain in this soil as such, but is changed or destroyed by the oxidation which is going on in soils of this character.

Effect of Salicylic Aldehyde and Vanillin on Different Soils and the Action of Fertilizers in Ameliorating their Harmful Properties.

Since it has been shown that vanillin and salicylic aldehyde have an effect which differs in different soils—that is, in some soils they persist and remain as such to have their effect on crops, while in others they are changed or destroyed by the life-processes

of the soil, and added aldehydes have no harmful influence—other experiments were made with a number of different soils in pots to further determine the effect of these compounds on other soils of widely different characteristics.

In this work cowpeas and clover were principally grown. The soils used were gotten through soil survey parties of the U. S. Bureau of Soils in different parts of the country. In each case the soil secured was a representative one of the area from which it was taken, and in most cases it was the principal soil type encountered in that area.

This study was confined to the growth of plants in the soil to which aldehydes were added, both with and without fertilizers. The effect of the aldehyde on the soil was determined, and the effect of the commonly used fertilizers and lime and manganese in overcoming or ameliorating the action of the compounds was studied. No attempt was made to determine whether or not the aldehydes persisted in the soil as such or were changed or destroyed.

In all, nine different soils were used in this experiment; namely, the Cecil clay loam from North Carolina, the Orangeburg sandy loam from Georgia, Chester loam from Virginia, Chester loam from Maryland, Cecil sandy loam from Georgia, Volusia loam from Ohio, Holston fine sandy loam from West Virginia, Norfolk sand from Alabama, and Collington fine sandy loam from New Jersey.

The effect of both vanillin and salicylic aldehyde was quite different in these different soils. In four of them the added aldehydes produced no harmful effect on the crops grown, while in the other five the growth was reduced very markedly in some, while in others the effect was moderate. In these soils lime overcame the action of the compounds to a great extent; phosphates, nitrates, and manganese each had a marked influence.

The results of the tests on each soil are given in Table XII.

In these experiments clover, cowpeas, and wheat were grown in the soil in paraffin wire pots, and in a few cases stone crocks were used. Each pot holds approximately 12 pounds of soil. Where cowpeas were grown, four plants were grown in each pot, and in the case of clover 0.05 gramme of seed was sown in each pot. The cowpeas were grown in about six weeks, and the clover in three and a half to four months.

TABLE XII.

Effect of Aldehyde on Growth in Nine Different Soils and the Action of Fertilisers in Modifying their Effects. (Yield Expressed in Grams of Green Matter Per Pot.)

Soil	Cecil clay loam			Orange-burg sandy loam		Chester Loam (Va.)				Chester Loam (Md.)		Cecil sandy loam			Volusia loam		Hol-ston fine sandy loam	Nor-folk sand	Collington fine sandy loam	
Experiment No.	1	2	3	1	2	1	2	3	4	1	2	1	2	3	1	2	1	1	1	2
Plant	Cowpeas	Clover	Cowpeas	Cowpeas	Clover	Cowpeas	Clover	Cowpeas	Clover	Clover	Cowpeas	Clover	Clover	Cowpeas	Wheat	Clover	Cowpeas	Cowpeas	Clover	Cowpeas
Untreated soil	6.3	75.0	9.5	7.5	55.2	8.2	32.6	5.5	57.0	31.2	10.3	52.5	62.2	6.7	4.90	26.4	31.8	8.7	42.0	14.1
Untreated soil + salicylic aldehyde	2.2*	65.7	—	4.5	27.1	7.0	31.8	5.0	59.2	31.0	—	11.2	55.0	2.5	3.50	—	33.5	5.7	39.5	—
Untreated soil + salicylic aldehyde + acid phosphate	5.5	67.0	—	6.2	56.3	7.8	36.8	—	—	33.7	—	28.0	—	—	—	—	35.4	9.8	41.0	—
Untreated soil + salicylic aldehyde + sodium nitrate	4.8	63.5	—	5.2	33.2	6.5	35.6	—	—	22.3	—	25.0	—	—	—	—	34.7	7.0	47.5	—
Untreated soil + salicylic aldehyde + manganese sulphate	—	—	—	—	—	—	—	4.9	63.1	—	—	—	73.1	4.0	4.15	—	—	—	—	—
Untreated soil + salicylic aldehyde + ferrous sulphate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.00	—	—	—	—	—
Untreated soil + lime + salicylic aldehyde	3.1	87.0	—	7.9	62.3	8.0	32.5	—	—	36.8	—	70.0	—	—	—	—	—	—	80.2	—
Untreated soil + lime + salicylic aldehyde + acid phosphate	5.3	123.5	—	7.9	63.8	7.9	32.8	—	—	40.3	—	82.5	—	—	—	—	—	—	84.5	—
Untreated soil + lime + salicylic aldehyde + sodium nitrate	4.9	102.0	—	9.0	63.4	7.6	33.2	—	—	31.5	—	47.5	—	—	—	—	—	—	90.0	—
Untreated soil + vanillin	—	—	6.6	—	—	—	—	—	—	—	9.5	—	—	—	4.25	21.2	30.2	5.9	—	16.4
Untreated soil + vanillin + acid phosphate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	34.7	—	—	—
Untreated soil + vanillin + sodium nitrate	—	—	8.3	—	—	—	—	—	—	—	9.7	—	—	—	—	—	33.2	—	—	16.3
Untreated soil + vanillin + manganese sulphate	—	—	9.5	—	—	—	—	—	—	—	9.2	—	—	—	4.55	42.2	—	—	—	15.5
Untreated soil + vanillin + ferrous sulphate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.15	—	—	—	—	—
Untreated soil + lime + vanillin	—	—	10.0	—	—	—	—	—	—	—	10.2	—	—	—	—	—	—	—	—	17.1
Untreated soil + lime + vanillin + sodium nitrate	—	—	—	—	—	—	—	—	—	—	9.8	—	—	—	—	45.9	—	—	—	—
Untreated soil + lime + vanillin + manganese sulphate	—	—	11.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Untreated soil + acid phosphate	5.8	90.5	—	8.3	68.7	8.5	42.7	—	—	39.4	—	58.3	—	—	—	—	36.4	15.5	46.9	16.2
Untreated soil + sodium nitrate	5.0	80.0	—	8.0	64.4	7.0	34.3	—	—	30.2	11.5	60.2	—	—	—	—	33.0	11.7	50.9	17.8
Untreated soil + manganese sulphate	—	—	—	—	—	—	—	6.0	60.2	—	11.4	—	69.5	7.6	5.10	31.7	—	—	—	15.0
Untreated soil + ferrous sulphate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.45	—	—	—	—	—
Untreated soil + lime sulphate	7.5	90.9	—	9.0	62.1	8.6	33.6	—	—	38.0	—	72.9	—	—	—	37.9	—	—	83.3	—
Untreated sulphate + lime + acid phosphate	4.5	114.2	—	10.2	61.6	7.8	44.0	—	—	37.7	—	80.0	—	—	—	—	—	—	85.9	—
Untreated soil + lime + sodium nitrate	4.0	107.7	—	9.5	64.0	7.9	38.0	—	—	39.7	—	75.5	—	—	—	—	—	—	91.2	—
Untreated soil + lime + manganese sulphate	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	38.2	—	—	—	—

* 2 plants died, figures represent weight of 2 plants only.

The fertilizing materials used in these experiments were all applied before the soil was potted and planted. They were well mixed in the soil. The salicylic aldehyde and vanillin were applied in three applications. One-third of the total amount was added to the soil before planting, one-third two to three weeks after planting, and the remaining one-third was added two to three weeks after the second application. In these experiments salicylic aldehyde was used at the rate of 200 pounds per acre, vanillin 400 pounds per acre, acid phosphate 360 pounds, sodium nitrate 180 pounds, lime ($CaCO_3$) two tons per acre, manganese sulphate 100 pounds, and ferrous sulphate 50 pounds per acre. This work was conducted in the greenhouse in the fall of 1914 and the winter and spring of 1915.

Cecil Clay Loam.—The soil used in this experiment was taken from Lincoln County, North Carolina, in the Piedmont Plateau region (2). The surface soil is brown to red clay loam, ranging in depth from 5 to 8 inches. The subsoil is a red stiff clay, brittle when dry, but sticky and plastic when wet. The soil is residual in origin, having been derived from the weathering of the rock formations, composed mainly of quartz and feldspar, with some mica and hornblends. It is fertilized usually with acid phosphate and produces about 300 pounds of lint cotton per acre. When the soil was collected the field was growing cowpeas. For three years previous to this it grew cotton. The field was reported as being well drained.

A laboratory examination showed the soil to be acid; its oxidative power was poor—a little less than the run of average field soils.

The effect of salicylic aldehyde in the Cecil clay loam was tested by growing cowpeas and clover, and the results are given in Table XII, experiments Nos. 1 and 2.

The aldehyde reduced the growth of both cowpeas and clover in this soil. Two of the cowpea plants in the pots treated with the aldehyde, unfertilized and limed, were killed; the weights given are the weights of the two plants that were living at the end of the experiment. The untreated soil produced 6.3 grammes green weight, and the salicylic aldehyde pot produced 2.2 grammes for two plants, or 4.4 grammes calculated for four plants. With acid phosphate the aldehyde was less harmful, and the sodium

nitrate only slightly less. In the limed soil the effect was also marked.

The growth of clover was also reduced by the aldehyde used alone and with fertilizers, but it had practically no effect in the limed soil. Lime and acid phosphate overcame its effect entirely, and lime and sodium nitrate to a great extent.

The effect of vanillin with and without certain fertilizers was also tested in this soil. In this experiment cowpea plants were grown; the results are given in experiment No. 3. Vanillin proved harmful, reducing the growth of the cowpeas from 9.5 grammes to 6.6 grammes. Sodium nitrate partly overcame its effect, and lime and manganese sulphate overcame the harmful

FIG. 39.

Effect of vanillin on cowpeas in Cecil clay loam and the action of lime and manganese in altering its effects: No. 1, soil untreated; No. 2, vanillin; No. 3, same + sodium nitrate; No. 4, same + lime; No. 5, same + manganese.

influence entirely. The effect of vanillin and the ameliorating effect of the fertilizers are shown in Fig. 39.

Orangeburg Sandy Loan.—The Orangeburg sandy loam (73) used in the aldehyde test was taken from Clay County, near Fort Gaines, Ga. It is a coastal plains soil and is a grayish loamy sand, underlain at 5 or 6 inches by light-reddish loamy sand. The subsoil is a red, friable sandy clay which extends to a depth of 3 feet or more. It is not a productive soil, and requires heavy applications of fertilizers to maintain a satisfactory crop. General farm crops are grown on the type. The field from which the sample was taken was growing cotton, and has grown cotton for the past 12 years. The soil was found to be acid, and its oxidizing power was very low.

Cowpeas and clover were used to test the effect of salicylic aldehyde, with and without fertilizers, in the Orangeburg sandy loam. The green weight yields are given in Table XII, experiments Nos. 1 and 2.

By an examination of the table it is seen that salicylic aldehyde reduced the growth of both cowpeas and clover. The green weight of the cowpeas was reduced from 7.5 grammes to 4.5 grammes. With acid phosphate the aldehyde reduced growth to only 6.2 grammes. Sodium nitrate also lessened the effect of the aldehyde slightly, but not so much as the phosphate fertilizer. The aldehyde was only slightly harmful in the limed soil.

The aldehyde reduced the green weight of the clover from 55.2 grammes to 27.1 grammes. Its harmful effect was partly

FIG. 40.

Effect of salicylic aldehyde on clover on unlimed Orangeburg sandy loam, and the action of fertilizers in destroying its effects: No. 1, soil untreated; No. 2, salicylic aldehyde; No. 3, same plus acid phosphate; No. 4, acid phosphate; No. 5 salicylic aldehyde plus sodium nitrate; No. 6, sodium nitrate.

overcome by phosphate fertilizers and entirely overcome by lime. Sodium nitrate had only a small influence in lessening its harmfulness in this soil. The growth of the clover as affected by salicylic aldehyde in this soil and the action of fertilizers in overcoming its effect are shown in Figs. 40 and 41. In Fig. 40 the effect of the aldehyde on clover is shown in pot No. 2, and it is here seen that the growth is much smaller than its check pot No. 1. Pot No. 3, which contains phosphate with aldehyde, has produced as good growth as the check. It is also seen in pot No. 5, which had aldehyde with nitrate, that the growth is about the same as in the pot which has aldehyde alone. In the limed set shown in Fig. 41 the growth in all the pots appears about the same.

Chester Loam (Virginia).—The next experiment was made

on the Chester loam from McLain, Fairfax County, Virginia (14). The field from which the soil was taken produces excellent crops of corn, grass, and wheat. It is naturally a productive soil, and has been manured well for several years with stable and barnyard manure. The Chester soil occupies an extensive area in Fairfax County. The surface soil is a brown to yellowish-brown, friable loam, 8 to 12 inches deep; the subsoil is yellowish-brown clay loam. The soil lies in the Piedmont Plateau and has weathered deep its parent rock. It is well drained, and the soil responds to general fertilizer treatments. The soil is neutral in reaction; it has a very strong oxidizing power.

FIG. 41.

Effect of salicylic aldehyde on clover in limed Orangeburg sandy loam: No. 1, soil untreated; No. 2, salicylic aldehyde; No. 3, salicylic aldehyde + acid phosphate; No. 4, acid phosphate; No. 5, salicylic aldehyde + sodium nitrate; No. 6, sodium nitrate.

Clover and cowpeas were grown to study the effect of salicylic aldehyde in the Chester loam; the results are given in Table XII, experiments Nos. 1, 2, 3, and 4. As seen by the green weight figures, the aldehyde had only a very slight effect in reducing growth. This is true with both cowpeas and clover. The slight differences that exist show a slight harmfulness of the aldehyde, and these differences are so very slight that it is easily within the range of experimental error, and it seems fair to conclude that salicylic aldehyde has no harmful effect in this productive strong soil.

Chester Loam (Maryland).—This sample of Chester loam was taken from Montgomery County, Maryland (13), and, like the Chester loam from Virginia, it is a productive fertile soil, having strong oxidizing power, and is otherwise a strong soil on

which good cultural methods have been practised. The soil has been fertilized with commercial fertilizer from year to year, and in 1913 was limed heavily. The soil produces good yields of corn, wheat, and hay. It is neutral in reaction.

The soil lies in the Piedmont Plateau and is derived from the underlying rock. It is the most extensive type in Montgomery County; is easily tilled and does not clod or break badly on drying.

As seen in Table XII, experiment No. 1, salicylic aldehyde had no injurious effect on this soil. Clover was grown and a good crop produced. An examination of the table will show that the only depression from the salicylic aldehyde treatment was when used with sodium nitrate. This is true in both the unlimed and limed pots. From this it would seem that the effect of salicylic

FIG. 42.

Effect of salicylic aldehyde on clover in unlimed Chester loam: No. 1, soil untreated; No. 2, salicylic aldehyde; No. 3, same + acid phosphate; No. 4 acid phosphate; No. 5, salicylic aldehyde + sodium nitrate; No. 6, sodium nitrate.

aldehyde was worse with sodium nitrate fertilizers. This, however, has not been the case with the other experiments made, and may be merely an accident here. The uniform growth from each of the treatments is shown in Fig. 42.

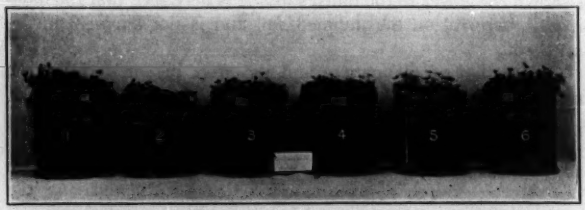
An experiment testing the effect of vanillin on this soil was also made, and the results are given in Table XII, experiment No. 2. Cowpeas were grown. Vanillin, like the salicylic aldehyde, had no harmful action; the green weight figures show that all of the treatments made about equal growth.

Cecil Sandy Loam.—The Cecil sandy loam on which the pot tests were made was taken from near Decatur, Dekalb County, Georgia (29). It is a gray to grayish-brown sandy loam; the subsoil is a red, friable sandy loam which grades into a heavy,

stiff red clay. It is a widely distributed type of the Piedmont Plateau. The field from which the soil was taken grew cotton for the past three years, producing about one-half bale per acre.

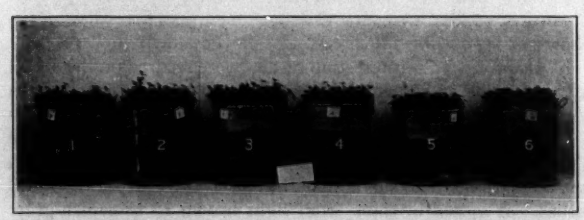
When examined in the laboratory the soil was found to be acid. Its oxidizing power was very low, about one-half as strong as the Chester loam, and it was without reducing power.

FIG. 43.



Effect of salicylic aldehyde on clover in unlimed Cecil sandy loam: No. 1, soil untreated; No. 2, salicylic aldehyde; No. 3, same + acid phosphate; No. 4, acid phosphate; No. 5, salicylic aldehyde + sodium nitrate; No. 6, sodium nitrate.

FIG. 44.



Effect of salicylic aldehyde on clover in limed Cecil sandy loam: No. 1, soil untreated; No. 2, salicylic aldehyde; No. 3, same + acid phosphate; No. 4, acid phosphate; No. 5, salicylic aldehyde + sodium nitrate; No. 6, sodium nitrate.

The first test with salicylic aldehyde and fertilizers was made by growing clover in paraffin wire pots holding ten pounds of soil.

The aldehyde proved to be very harmful in this soil, as shown in Table XII, experiment No. 1. The yield of clover was reduced in weight from 52.5 grammes for the check to 11.2 grammes. With acid phosphate fertilizers it was not quite so harmful. The

acid phosphate pot yielded 58.3 grammes, and aldehyde plus phosphate 28.0 grammes. The phosphate had a slight effect in ameliorating the harmfulness of the compound. With sodium nitrate the difference in yield was greater. The nitrate pot gave 60.2 grammes green weight, while the pot with nitrate plus aldehyde gave only 25.0 grammes green weight. The aldehyde had no harmful effect on the limed soil. In Fig. 43 is shown the clover with different treatments in the unlimed soil, and in Fig. 44 is shown the clover in the limed soil. It is here seen that the aldehyde is harmful on the unlimed soil and is not harmful in the limed soil.

The action of manganese and its effect in ameliorating the harmfulness of salicylic aldehyde were also studied in this soil. An experiment was made growing cowpeas and one growing clover.

Considering the cowpeas first, it is seen that the aldehyde reduced the growth approximately 50 per cent., and that the manganese lessened its harmfulness.

With the clover the aldehyde reduced the growth greatly, but not so much as it did the cowpeas. In this test the manganese entirely overcame its harmful effect. The clover is shown growing in pots with different treatments in Fig. 45.

In this soil, at least, manganese is about as effective as phosphates in destroying the effects of salicylic aldehyde.

Volusia Loam.—Interesting results were secured on the action of manganese on the effect of vanillin and salicylic aldehyde in Volusia loam.

The soil was taken from Portage County, Ohio (33). The Volusia loam is of glacial origin and is largely derived from unmodified till. The surface soil has an average depth of 6 to 8 inches. It varies in color from light brown to brownish-gray. The subsoil is a pale yellow loam or silty loam and somewhat heavier than the surface soil. Gravel and small stone, and to some extent boulders, are found scattered over the surface and through the soil mass. It is a good general farming soil, growing corn and small grain well.

The soil used in these tests was found to be acid; it has a good oxidizing power.

The first experiment made with this soil was in small paraffin wire pots holding 400 grammes of soil. Five pots were used for

each treatment. Six wheat plants were grown in each pot for about one month. The materials used were all added and mixed thoroughly with the soil before potting and planting. Vanillin was used in amounts of 400 pounds per acre, and salicylic aldehyde 200 pounds per acre. Wheat was planted January 28 and grew until February 25, 1915. The green weights are given in Table XII, experiment No. 1. The weights for each treatment represent the growth in five pots, thirty plants in all.

The wheat plants were grown in these small pots for only 28 days, yet some indications of the action of vanillin and salicylic aldehyde and the effect of manganese and iron on their action in

FIG. 45.

Effect of salicylic aldehyde on clover in Cecil sandy loam: No. 1, soil untreated; No. 2, manganese sulphate; No. 3, salicylic aldehyde; No. 4, salicylic aldehyde + manganese sulphate.

this soil are shown. Vanillin reduced growth slightly; manganese had some effect on its action, for the vanillin produced slightly heavier plants where manganese was applied to the soil. The iron sulphate seems to have had no beneficial action on the harmfulness of vanillin.

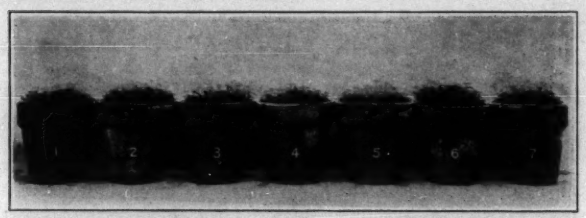
Salicylic aldehyde was also slightly harmful, even more so than the vanillin, and both manganese and iron ameliorated its harmfulness.

Another experiment was made to further test the influence of the catalytic fertilizers on the action of vanillin. This time clover was grown in 8-inch earthenware pots, which hold 8 pounds of

soil. The vanillin was added at the rate of 500 pounds, periodically as described at the beginning of this chapter.

As seen in the table, experiment No. 2, this soil responded well to manganese and to lime. Vanillin in the amount used, 500 pounds per acre, produced a decreased yield, but this decreased growth is much smaller than in some soils as recorded in this paper. Both manganese and lime entirely overcame the effect of the vanillin. The growths in the pots receiving vanillin, which were fertilized with manganese and with manganese plus lime, were the best in the series. The growth of the clover as affected by the different treatments is shown in Fig. 46.

FIG. 46.



Effect of vanillin on clover in Volusia loam, and the action of manganese and lime in overcoming its effect: No. 1, soil untreated; No. 2, $MnSO_4$; No. 3, lime; No. 4, lime + $MnSO_4$; No. 5, vanillin; No. 6, same + $MnSO_4$; No. 7, same + $MnSO_4$ + lime.

Holston Fine Sandy Loam.—The Holston fine sandy loam used in the aldehyde experiment is naturally a strong productive soil. The field from which the soil was taken was manured yearly with stable manure in amounts of 20 to 25 loads per acre, and 250 pounds per acre of a high-grade fertilizer was applied. The field was in corn when the sample was taken; previously it had grown vegetables for years. The soil was neutral and had a strong oxidizing power.

The Holston loam (27) is a brownish, light, fine sandy loam and is underlaid at about 10 inches by yellow, compact, fine sandy loam. Drainage is good. The soil occurs on old alluvial terraces and consists principally of material washed from gray shales and sandstones. It is easy to cultivate, requiring only light implements, and responds readily to manure and fertilizers.

The experiment was conducted in paraffin wire pots holding 10 pounds of soils, and four cowpeas were grown in each pot. Vanillin was used at the rate of 400 pounds per acre, salicylic aldehyde, acid phosphate, and sodium nitrate at the rate of 200, 360, and 180 pounds, respectively, per acre. The cowpeas were planted October 22, 1915, and made an excellent growth, producing large stalks and luxuriant foliage. The green weights of the peas were taken December 8.

As seen in Table XII, neither salicylic aldehyde nor vanillin had any harmful effect. The untreated soil produced 31.8 grammes green weight, salicylic aldehyde 33.5 grammes, and vanillin 30.2 grammes. The growth in the fertilized pots containing the aldehydes was also greater than the untreated soil and about the same as the pots which contained the fertilizers without any aldehyde. It is apparent, then, that the aldehydes do not have any bad effects in this soil.

Norfolk Sand.—One of the samples of Norfolk sand used in these tests was taken from near Clayton, Barbour County, Alabama (72). This soil type occupies nearly level to rolling uplands throughout the Coastal Plain, and has been derived from unconsolidated sedimentary material. This soil is well drained, sometimes excessively. Its porous texture allows it to absorb nearly all the rainfall, and in wet seasons it becomes waterlogged. The surface soil is a loose, incoherent, grayish sand from 4 to 6 inches deep. The subsoil is a pale-yellow sand which extends to a depth of 3 feet. Iron concretions are common, and fine gravel occurs. The soil produces about one-fourth bale of cotton and about 10 bushels of corn per acre.

Cowpeas were grown in the test with this soil, and the effects of both salicylic aldehyde and vanillin were determined. The results are given in Table XII, in the Norfolk sand column.

Salicylic aldehyde reduced growth from 8.7 grammes for the check to 5.7 grammes. The peas responded well to both acid phosphate and sodium nitrate, especially the phosphate. The acid phosphate also increased the growth considerably in the pot to which the aldehyde was added, partly overcoming its harmful effect. Vanillin was also harmful in this soil. The green weight of the vanillin-treated pot was 5.9 grammes, against 8.7 grammes for the untreated pot.

Collington Fine Sandy Soil.—This soil was taken from a field

near Marlton, N. J. It lies within the Atlantic Coastal Plain and is derived from the beds of unconsolidated sand, sandy clay, gravel, and marl. These beds are composed of material which was transported from older land areas and deposited under marine conditions. The Collington fine sandy loam consists of a brown, fine sandy loam underlaid at about 8 to 12 inches by yellowish, fine sandy loam (34). The lower subsoil is more friable than the upper subsoil. This type is the most important soil of the Camden area. It is chiefly devoted to the growing of potatoes, tomatoes, and vegetable crops, and yields well.

The soils, as a rule, are highly manured. The field from which the sample was taken has grown potatoes for five years, and was highly manured with stable manure and commercial fertilizers. Lime was added in 1914. The sample, however, when taken from the field and examined in the laboratory, was found to be acid.

Two experiments in pots were made with the Collington fine sandy loam. In the first, testing the effect of salicylic aldehyde, clover was grown, the results of which are given in Table XII.

As is seen in the green weight column in the table, the salicylic aldehyde had practically no effect in this soil. The clover responded well to the fertilizers and lime. In any case, there was only a very slight reduction in growth due to the aldehyde, and there was no effect whatever in the limed soil.

In the second experiment the effect of vanillin and the action of nitrate, manganese, and lime in ameliorating its effect were studied. In this case cowpeas were grown. No harmful effect was observed from the added vanillin; in fact, there was a slight increased growth in the vanillin-treated pot. Sodium nitrate, manganese, and lime each produced an increase over the check. From the results of the two experiments it will have to be concluded that aldehydes are not harmful in this soil.

(To be continued.)

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS,

Professor of Meteorological Physics, United States Weather Bureau.

CHAPTER XV (*Continued*).

AURORA POLARIS

The aurora polaris is a well-known but imperfectly understood luminous phenomenon of the upper atmosphere, of which Figs. 120 and 121, from Störmer's numerous photographs, are good examples.

Types.—While no two auroras are exactly alike, several types have been recognized, such as arcs, bands, rays, curtains or draperies, coronas, luminous patches, and diffuse glows. The arcs normal to the magnetic meridian, often, but not always, reach the horizon. Their under edge is rather sharply defined, so that by contrast the adjacent portion of the sky appears exceptionally dark. The rays, sometimes extending upward from an arch, at other times isolated, are parallel to the lines of magnetic force. Many auroras are quiescent, others exceedingly changeable, flitting from side to side like wandering searchlights, and in some cases even waving like giant tongues of flame.

Latitude Variation.—The aurora of the northern hemisphere occurs most frequently, about 100 per year, at the latitudes 60° (over the North Atlantic and North America) to 70° (off the coast of Siberia). Its frequency appears to be less within this boundary, while with decrease of latitude it falls off so rapidly that even in southern Europe it is a rare phenomenon. At the same latitude it is distinctly more frequent in North America than in either Europe or Asia.

The distribution of auroras in the southern hemisphere is

* Concluded from page 370, Vol. 186, September, 1918.

not so well known, but it appears to be similar, in general, to that of the northern.

Periodicity.—It is well established that on the average auroras are more numerous during years of sun spot maxima than during years of spot minima. They also appear to be more numerous before midnight than after. Relations of frequency to phase of the moon, season, et cetera, have also been discussed, but with no conclusive results.

FIG. 120.

Aurora, February 28, 1910. (Störmer.)

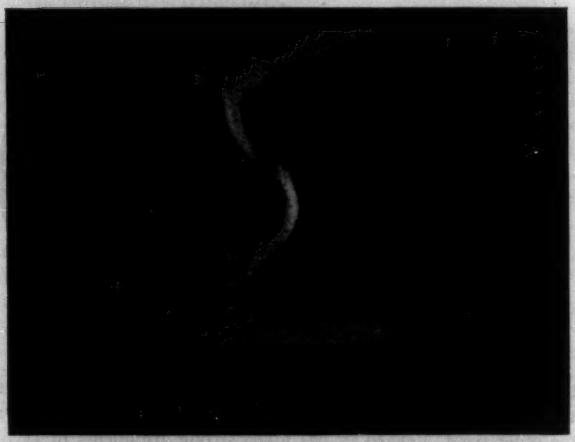
Color.—Many auroras are practically white. Red, yellow and green are also common auroral colors. Some streaks and bands are reddish through their lower (northern) portion, then yellowish, and finally greenish through the higher portions. Much of the light is due to nitrogen bands, but the source of the most prominent line of the auroral spectrum, λ .557 μ (green), is not known. It has often been attributed to krypton, but other conspicuous krypton lines are absent; besides krypton is too

heavy to exist at auroral heights in sufficient abundance to produce a spectrum of such brilliance.

There is good evidence that this green light, the light that produces the "auroral line," is always present in the sky, though whether wholly of auroral origin, or due in part to bombardment by meteoric dust, or to some other cause, is not known.

Height.—The problem of the height of auroras has often been

FIG. 121.



Aurora, March 3, 1910. (Störmer.)

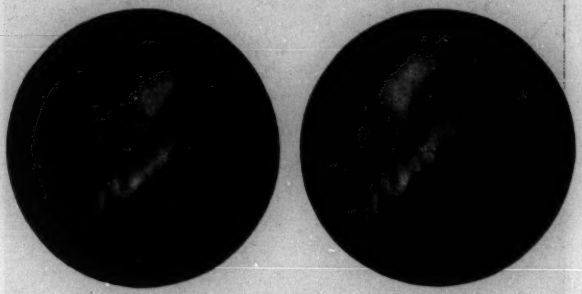
investigated, but only recently solved. By simultaneously photographing the same aurora from two stations against a common background of stars, Fig. 122, and measuring the parallax obtained, Störmer,[163] and Vegard and Krogness[164] have secured many excellent height measurements. The upper limits of the auroral light vary from about 100 kilometers to over 300 kilo-

[163] *Terr. Magnet. and Atmos. Elec.*, 21, p. 157, 1916.
[164] *Terr. Magnet. and Atmos. Elec.*, 21, p. 169, 1916.

meters; and the lower limits from perhaps 85 kilometers to 170 kilometers, with two well-defined maxima, one at 100 kilometers, the other at 106 kilometers.

Cause.—The fact that brilliant shifting auroras are accompanied by magnetic storms renders it practically certain that they, and presumably therefore all auroras, are due to electric discharges; and the further fact that they vary in frequency with the sunspot period indicates that this current either comes from or is induced by the sun. For some time it was thought prob-

FIG. 122.



Parallactic auroral photographs for determining altitude. (Störmer.)

able that auroras are caused by negative particles shot off from the sun, and entrapped by the magnetic field of the earth. On the other hand, Vegard [165] has given strong arguments in favor of the α particle which is positively charged, and Störmer[166] has found at least one case that required the positive charge to account for the observed magnetic disturbance.

The evidence, then, while not conclusive, indicates that auroras are due to streams of α particles in the upper atmosphere shot off by radioactive substances in the sun.

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[165] *Phil. Mag.*, 23, p. 211, 1912.

[166] *Terr. Magnet. and Atmos. Elec.*, 20, p. 1, 1915.

APPENDIX.

GRADIENT WIND VELOCITY TABLES.

To be used only in the absence of local disturbances—thunderstorms, line squalls, and the like—and when the isobars, as drawn, are free from any considerable reduction or other errors. Also to be used with discretion in the case of east winds in the middle latitudes, since at an altitude of 1 kilometer or more their actual velocities are likely to be less than the computed, as explained on page 670, Nov., 1917.

To find from the following tables the probable wind velocity at 1 to 2 kilometers elevation over any given place, one notes, *a*, the current system of winds, cyclonic or anticyclonic, at that place (this determines which table to use); *b*, the latitude of the place in question (this determines the latitude division of the table in which the desired value is to be found); *c*, the pressure gradient shown on the concurrent weather map in terms of the difference of the barometer reading in millimeters per 100 kilometers at right angles to the nearest isobar (this, through the closest tabulated gradient, locates the gradient division of the value sought); and, finally, *d*, the radius of curvature, in kilometers, of this isobar (a sufficiently close practical value of *r*) at the place in question, on line with which the desired velocity is given in meters per second, kilometers per hour, and miles per hour. The wind at the given levels is roughly parallel to the corresponding surface isobar, and so directed that on following it one will have the lower pressure to his left.

In using these tables in conjunction with weather maps whose barometric interval is 0.1 inch, the interval used in the United States, it is only necessary in taking step *c* to note the number of miles between the 0.1 inch isobars and then select from the second expressions in the first columns the nearest to an equal gradient.

The actual gradient, radius of curvature, density, and latitude usually will all differ somewhat from the tabulated values, but as the latter, except the density, which may be computed approximately, are given for small intervals it would be easy to add, with their proper signs, interpolated corrections. In practice, how-

ever, this will hardly be necessary, partly because of the great number of intervals directly supplied by the tables themselves, and partly because actual velocities and computed gradient velocities are likely to differ too much to justify minute corrections. They differ because the atmosphere never attains to a fixed or steady state of motion; because the actual density is likely to differ from that assumed; and because the gradient at the level for which computation is made is not, as a rule, exactly the same as that given on the maps.

In regions of great elevation, 1 kilometer or more, the isobaric lines, if drawn, as they commonly are, in accordance with values obtained by reduction of the barometer to sea level, may be seriously in error during both unusually warm and exceptionally cold weather. Obviously, therefore, it is not safe, at such times and places, to use the reduced distribution of isobars for the calculation of gradient winds—nor, indeed, for any other purpose.

The first line in each section of the anticyclonic table gives the maximum velocity for the given density and pressure gradient and the corresponding radius of curvature of the path. It will be noticed that this limiting radius grows smaller as the gradient is decreased, in accordance with the fact that steep gradients and strong winds can not occur near the center of an anticyclonic region.

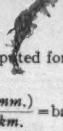

TABLE I.

Gradient Wind Velocity for Cyclonic Movement.

(Computed for $\rho = .0011$, a density that obtains at an elevation of about 1 kilometer above sea level.)

$\frac{\triangle B\ (mm.)}{100\ km.}$ = barometric gradient, or difference of barometric reading in millimeters per 100 kilometers at right angles to isobars = $\frac{\triangle B\ (\text{tenths } in.)}{158\ mi.}$

r = radius of curvature of isobars in kilometers.

$V\frac{m}{s}$ = velocity in meters per second.

$V\frac{km}{hr}$ = velocity in kilometers per hour.

$V\frac{mi}{hr}$ = velocity in miles per hour.

Latitude 25°.

$\frac{\triangle B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\triangle B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	2.73	9.83	6.11	$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	5.99	21.56	13.40
	200	3.13	11.27	7.00		200	7.38	26.57	16.51
	300	3.33	11.99	7.45		300	8.18	29.45	18.30
	400	3.45	12.42	7.72		400	8.71	31.36	19.49
	500	3.53	12.71	7.90		500	9.10	32.76	20.36
	600	3.58	12.89	8.01		600	9.40	33.84	21.03
	700	3.63	13.07	8.12		700	9.64	34.70	21.56
	800	3.66	13.18	8.19		800	9.83	35.39	21.99
	900	3.69	13.28	8.25		900	9.99	35.96	22.34
	1000	3.71	13.36	8.30		1000	10.13	36.47	22.66
	1200	3.74	13.46	8.36		1200	10.35	37.26	23.15
	1500	3.78	13.61	8.46		1500	10.58	38.09	23.67
	2000	3.81	13.72	8.53		2000	10.84	39.02	24.25
	3000	3.85	13.86	8.61		3000	11.12	40.03	24.87
	∞	3.93	14.15	8.79		∞	11.79	42.44	26.37
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	4.53	16.31	10.13	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	7.24	26.06	16.19
	200	5.45	19.62	12.19		200	9.06	32.62	20.27
	300	5.95	21.42	13.31		300	10.15	36.54	22.70
	400	6.27	22.57	14.02		400	10.90	39.24	24.38
	500	6.49	23.36	14.52		500	11.46	41.26	25.64
	600	6.66	23.98	14.90		600	11.90	42.84	26.62
	700	6.79	24.44	15.19		700	12.25	44.10	27.40
	800	6.90	24.84	15.43		800	12.54	45.14	28.05
	900	6.98	25.13	15.62		900	12.78	46.01	28.59
	1000	7.05	25.38	15.77		1000	12.99	46.76	29.05
	1200	7.17	25.81	16.04		1200	13.32	47.95	29.79
	1500	7.29	26.24	16.30		1500	13.69	49.28	30.62
	2000	7.42	26.71	16.60		2000	14.11	50.80	31.57
	3000	7.55	27.18	16.89		3000	14.58	52.49	32.62
	∞	7.86	28.30	17.58		∞	15.72	56.59	35.16

Latitude 25° (Continued.)

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	8.35	30.06	18.68	$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	14.59	52.52	32.63
	200	10.58	38.09	23.67		200	19.21	69.16	42.97
	300	11.94	42.98	26.71		300	22.28	80.21	49.84
	400	12.90	46.44	28.86		400	24.60	88.56	55.03
	500	13.63	49.07	30.49		500	26.44	95.18	59.14
	600	14.20	51.12	31.76		600	27.97	100.69	62.57
	700	14.67	52.81	32.81		700	29.27	105.37	65.47
	800	15.06	54.22	33.69		800	30.40	109.44	68.00
	900	15.39	55.40	34.42		900	31.38	112.97	70.20
	1000	15.67	56.41	35.05		1000	32.26	116.14	72.17
	1200	16.13	58.07	36.08		1200	33.74	121.46	75.47
	1500	16.65	59.94	37.25		1500	35.50	127.80	79.41
	2000	17.24	62.06	38.56		2000	37.64	135.50	84.20
	3000	17.92	64.51	40.08		3000	40.34	145.22	90.24
	∞	19.65	70.74	43.96		∞	49.13	176.87	109.90
$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	10.75	38.70	24.05	$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	16.23	58.43	36.31
	200	13.87	49.93	31.03		200	21.49	77.36	48.07
	300	15.87	57.13	35.50		300	25.04	90.14	56.01
	400	17.32	62.35	38.74		400	27.74	99.86	62.19
	500	18.44	66.38	41.23		500	29.92	107.71	66.93
	600	19.35	69.66	43.28		600	31.73	114.23	70.98
	700	20.11	72.40	44.99		700	33.28	119.81	74.45
	800	20.75	74.70	46.42		800	34.64	124.70	77.49
	900	21.30	76.68	47.65		900	35.83	128.99	80.15
	1000	21.78	78.41	48.72		1000	36.89	132.80	82.52
	1200	22.59	81.32	50.53		1200	38.71	139.36	86.59
	1500	23.50	84.60	52.57		1500	40.88	147.17	91.45
	2000	24.58	88.49	54.99		2000	43.56	156.82	97.44
	3000	25.87	93.13	57.87		3000	47.01	169.24	105.16
	∞	29.48	106.13	65.95		∞	58.96	212.26	131.90
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	12.79	46.04	28.61	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	19.15	68.94	42.84
	200	16.70	60.12	37.36		200	25.57	92.05	57.20
	300	19.26	69.34	43.09		300	29.99	107.96	67.08
	400	21.16	76.18	47.34		400	33.39	120.20	74.69
	500	22.65	81.54	50.67		500	36.17	130.21	80.91
	600	23.88	85.97	53.42		600	38.51	138.64	86.15
	700	24.92	89.71	55.74		700	40.53	145.91	90.67
	800	25.80	92.88	57.71		800	42.31	152.32	94.65
	900	26.58	95.69	59.46		900	43.89	158.00	98.18
	1000	27.26	98.14	60.98		1000	45.31	163.12	101.36
	1200	28.40	102.24	63.53		1200	47.77	171.97	106.86
	1500	29.74	107.06	66.52		1500	50.75	182.70	113.52
	2000	31.34	112.82	70.10		2000	54.51	196.24	121.94
	3000	33.31	119.92	74.52		3000	59.48	214.13	133.05
	∞	39.31	141.52	87.94		∞	78.61	283.00	175.85

Latitude 30°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	2.48	8.93	5.55	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	6.86	24.70	15.35
	200	2.79	10.04	6.24		200	8.43	30.35	18.86
	300	2.93	10.55	6.56		300	9.32	33.55	20.85
	400	3.01	10.84	6.74		400	9.92	35.71	22.19
	500	3.07	11.05	6.87		500	10.35	37.26	23.15
	600	3.10	11.16	6.93		600	10.68	38.45	23.89
	700	3.13	11.27	7.00		700	10.94	39.38	24.47
	800	3.15	11.34	7.05		800	11.16	40.18	24.97
	900	3.17	11.41	7.09		900	11.33	40.79	25.35
	1000	3.19	11.48	7.13		1000	11.48	41.33	25.68
	1200	3.21	11.56	7.18		1200	11.72	42.19	26.22
	1500	3.23	11.63	7.23		1500	11.98	43.13	26.80
	2000	3.25	11.70	7.27		2000	12.26	44.14	27.43
	3000	3.28	11.81	7.34		3000	12.57	45.25	28.11
	∞	3.32	11.95	7.43		∞	13.29	47.84	29.73
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	4.22	15.19	9.44	$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	7.95	28.62	17.78
	200	4.96	17.86	11.10		200	9.90	35.64	22.15
	300	5.34	19.22	11.94		300	11.04	39.74	24.69
	400	5.58	20.09	12.48		400	11.82	42.55	26.44
	500	5.74	20.66	12.84		500	12.40	44.64	27.74
	600	5.86	21.10	13.11		600	12.84	46.22	28.72
	700	5.95	21.42	13.31		700	13.20	47.52	29.53
	800	6.02	21.67	13.47		800	13.49	48.56	30.17
	900	6.08	21.89	13.60		900	13.74	49.46	30.73
	1000	6.13	22.07	13.71		1000	13.95	50.22	31.21
	1200	6.21	22.36	13.89		1200	14.28	51.41	31.95
	1500	6.28	22.61	14.05		1500	14.65	52.74	32.77
	2000	6.37	22.93	14.25		2000	15.06	54.22	33.69
	3000	6.56	23.62	14.68		3000	15.51	55.84	34.70
	∞	6.64	23.90	14.85		∞	16.61	59.80	37.16
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	5.63	20.27	12.60	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	10.32	37.15	23.08
	200	6.80	24.48	15.21		200	13.12	47.23	29.35
	300	7.44	26.78	16.64		300	14.85	53.46	33.22
	400	7.85	28.26	17.56		400	16.07	57.85	35.95
	500	8.15	29.34	18.23		500	17.00	61.20	38.03
	600	8.37	30.13	18.72		600	17.73	63.83	39.66
	700	8.54	30.74	19.10		700	18.33	65.99	41.00
	800	8.68	31.25	19.42		800	18.84	67.82	42.14
	900	8.79	31.64	19.66		900	19.27	69.37	43.10
	1000	8.89	32.00	19.88		1000	19.63	70.67	43.91
	1200	9.04	32.54	20.22		1200	20.24	72.86	45.27
	1500	9.20	33.12	20.58		1500	20.92	75.31	46.80
	2000	9.37	33.73	20.96		2000	21.69	78.08	48.52
	3000	9.55	34.38	21.36		3000	22.58	81.29	50.51
	∞	9.97	35.89	22.30		∞	24.92	89.71	55.74

Latitude 30° (Continued).

ΔB (mm.) / 100 km.	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}	ΔB (mm.) / 100 km.	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
2.0 mm. / 100 km. / 0.1 in. / 79 mi. =	100	12.34	44.42	27.60	3.0 mm. / 100 km. / 0.1 in. / 53 mi. =	100	15.77	56.77	35.27
	200	15.90	57.24	35.57		200	20.64	74.30	46.17
	300	18.16	65.38	40.62		300	23.85	85.86	53.35
	400	19.79	71.24	44.27		400	26.24	94.46	58.70
	500	21.06	75.82	47.11		500	28.13	101.27	62.93
	600	22.08	79.49	49.39		600	29.85	107.46	66.77
	700	22.93	82.55	51.29		700	31.00	111.60	69.34
	800	23.64	85.10	52.88		800	32.14	115.70	71.89
	900	24.26	87.34	54.27		900	33.12	119.23	74.09
	1000	24.79	89.24	55.45		1000	33.99	122.36	76.03
	1200	25.68	92.45	57.45		1200	35.46	127.66	79.32
	1500	26.71	96.16	59.75		1500	37.19	133.88	83.19
	2000	27.89	100.40	62.39		2000	39.27	141.37	87.84
	3000	29.30	105.48	65.54		3000	41.84	150.62	93.59
	∞	33.22	119.59	74.31		∞	49.84	179.42	111.49
2.5 mm. / 100 km. / 0.1 in. / 63 mi. =	100	14.14	50.90	31.63	4.0 mm. / 100 km. / 0.1 in. / 39 mi. =	100	18.67	67.21	41.76
	200	18.38	66.17	41.12		200	24.68	88.85	55.21
	300	21.13	76.97	47.27		300	28.73	103.43	64.27
	400	23.15	83.34	51.78		400	31.88	114.77	71.32
	500	24.74	89.06	55.34		500	34.26	123.34	76.64
	600	26.05	93.78	58.27		600	36.31	130.72	81.23
	700	27.12	97.63	60.66		700	38.06	137.02	85.14
	800	28.05	100.98	62.75		800	39.59	142.52	88.56
	900	28.85	103.86	64.54		900	40.93	147.35	91.56
	1000	29.55	106.38	66.10		1000	42.12	151.63	94.22
	1200	30.74	110.44	68.63		1200	44.16	158.98	98.79
	1500	32.11	115.60	71.83		1500	46.48	167.33	103.98
	2000	33.73	121.43	75.45		2000	49.59	178.52	110.93
	3000	35.70	128.52	79.86		3000	53.41	192.28	119.48
	∞	41.53	149.51	92.90		∞	66.45	239.22	148.64

Latitude 35°.

0.2 mm. / 100 km. / 0.1 in. / 789 mi. =	100	2.28	8.21	5.10	0.4 mm. / 100 km. / 0.1 in. / 395 mi. =	100	3.94	14.18	8.81
	200	2.52	9.07	5.64		200	4.55	16.38	10.18
	300	2.62	9.43	5.86		300	4.85	17.46	10.85
	400	2.68	9.65	6.00		400	5.04	18.14	11.27
	500	2.72	9.79	6.08		500	5.16	18.58	11.55
	600	2.75	9.90	6.15		600	5.24	18.86	11.72
	700	2.77	9.97	6.20		700	5.31	19.12	11.88
	800	2.78	10.01	6.22		800	5.36	19.30	11.99
	900	2.79	10.04	6.24		900	5.41	19.48	12.10
	1000	2.80	10.08	6.26		1000	5.44	19.58	12.17
	1200	2.82	10.15	6.31		1200	5.49	19.76	12.28
	1500	2.83	10.19	6.33		1500	5.55	19.98	12.42
	2000	2.85	10.26	6.38		2000	5.61	20.20	12.55
	3000	2.86	10.30	6.40		3000	5.67	20.41	12.68
	∞	2.90	10.44	6.49		∞	5.79	20.84	12.95

Latitude 35° (Continued).

$\frac{\triangle B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}	$\frac{\triangle B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	5.32	19.15	11.90	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	9.93	35.75	22.21
	200	6.31	22.72	14.12		200	12.45	44.82	27.85
	300	6.83	24.59	15.28		300	13.95	50.22	31.21
	400	7.16	25.78	16.02		400	15.00	54.00	33.55
	500	7.39	26.60	16.53		500	15.77	56.77	35.28
	600	7.55	27.18	16.89		600	16.38	58.97	36.64
	700	7.68	27.65	17.18		700	16.87	60.73	37.74
	800	7.78	28.01	17.40		800	17.28	62.21	38.66
	900	7.87	28.33	17.60		900	17.61	63.40	39.39
	1000	7.94	28.58	17.76		1000	17.90	64.44	40.04
	1200	8.04	28.94	17.98		1200	18.36	66.10	41.07
	1500	8.16	29.38	18.26		1500	18.88	67.97	42.24
	2000	8.28	29.81	18.52		2000	19.46	70.06	43.53
	3000	8.41	30.28	18.82		3000	20.11	72.40	44.99
	∞	8.69	31.28	19.48		∞	21.72	78.19	48.58
$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	6.51	23.44	14.57	$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	11.93	42.95	26.69
	200	7.88	28.37	17.63		200	15.18	54.65	33.96
	300	8.62	31.03	19.28		300	17.19	61.88	38.45
	400	9.11	32.80	20.38		400	18.61	67.00	41.63
	500	9.45	34.02	21.14		500	19.69	70.88	44.04
	600	9.71	34.96	21.72		600	20.55	73.98	45.97
	700	9.91	35.68	22.17		700	21.25	76.50	47.53
	800	10.07	36.25	22.52		800	21.84	78.62	48.85
	900	10.20	36.72	22.82		900	22.34	80.42	49.97
	1000	10.31	37.12	23.07		1000	22.77	81.97	50.93
	1200	10.49	37.76	23.46		1200	23.48	84.53	52.52
	1500	10.68	38.45	23.89		1500	24.27	87.37	54.29
	2000	10.88	39.17	24.34		2000	25.18	90.65	56.33
	3000	11.10	39.96	24.83		3000	26.22	94.33	58.61
	∞	11.58	41.69	25.90		∞	28.96	104.26	64.78
$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	7.59	27.32	16.98	$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	13.72	49.39	30.69
	200	9.31	33.52	20.83		200	17.63	63.47	39.44
	300	10.27	36.97	22.97		300	20.10	72.36	44.96
	400	10.92	39.31	24.43		400	21.89	78.80	48.96
	500	11.38	40.97	25.46		500	23.26	83.74	52.03
	600	11.74	42.26	26.26		600	24.37	87.73	54.51
	700	12.02	43.27	26.89		700	25.29	91.04	56.57
	800	12.24	44.06	27.38		800	26.06	93.82	58.30
	900	12.43	44.75	27.81		900	26.72	96.19	59.77
	1000	12.59	45.32	28.16		1000	27.30	98.28	61.07
	1200	12.84	46.22	28.72		1200	28.25	101.70	63.19
	1500	13.11	47.20	29.33		1500	29.34	105.62	65.63
	2000	13.41	48.28	30.00		2000	30.41	109.48	68.03
	3000	13.73	49.43	30.71		3000	32.10	115.56	71.81
	∞	14.48	52.13	32.39		∞	36.20	130.32	80.98

Latitude 35° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V^{\frac{m}{s}}$	$V^{\frac{km}{hr}}$	$V^{\frac{mi}{hr}}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V^{\frac{m}{s}}$	$V^{\frac{km}{hr}}$	$V^{\frac{mi}{hr}}$
$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	15.34	55.22	34.31	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	18.22	65.59	40.76
	200	19.86	71.50	44.43		200	23.87	85.93	53.39
	300	22.77	81.97	50.93		300	27.59	99.32	61.71
	400	24.91	89.68	55.73		400	30.37	109.33	67.93
	500	26.57	95.65	59.43		500	32.57	117.25	72.86
	600	27.91	100.48	62.44		600	34.38	123.77	76.91
	700	29.04	104.54	64.96		700	35.91	129.28	80.33
	800	30.00	108.00	67.11		800	37.22	133.99	83.26
	900	30.82	110.95	68.94		900	38.37	138.13	85.83
	1000	31.55	113.58	70.58		1000	39.38	141.77	88.09
	1200	32.76	117.94	73.28		1200	41.10	147.96	91.94
	1500	34.15	122.94	76.39		1500	43.11	155.20	96.44
	2000	35.79	128.84	80.06		2000	45.54	163.94	101.87
	3000	37.76	135.94	84.47		3000	48.54	174.74	108.58
	∞	43.44	156.38	97.17		∞	57.92	208.51	129.56

Latitude 40°.

$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	2.11	7.60	4.72	$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	5.04	18.14	11.27
	200	2.30	8.28	5.14		200	5.90	21.24	13.20
	300	2.38	8.57	5.33		300	6.33	22.79	14.16
	400	2.43	8.75	5.44		400	6.60	23.76	14.76
	500	2.46	8.86	5.51		500	6.78	24.41	15.17
	600	2.48	8.93	5.55		600	6.91	24.88	15.46
	700	2.49	8.96	5.57		700	7.01	25.24	15.68
	800	2.50	9.00	5.59		800	7.08	25.49	15.84
	900	2.51	9.04	5.62		900	7.15	25.74	15.99
	1000	2.52	9.07	5.63		1000	7.20	25.92	16.11
	1200	2.53	9.11	5.66		1200	7.28	26.21	16.29
	1500	2.54	9.14	5.68		1500	7.37	26.53	16.49
	2000	2.55	9.18	5.70		2000	7.46	26.86	16.69
	3000	2.56	9.22	5.73		3000	7.55	27.18	16.89
	∞	2.58	9.29	5.77		∞	7.75	27.90	17.34
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	3.71	13.36	8.30	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	6.23	22.43	13.94
	200	4.22	15.19	9.44		200	7.41	26.68	16.58
	300	4.46	16.06	9.98		300	8.04	28.94	17.98
	400	4.61	16.60	10.31		400	8.44	30.38	18.88
	500	4.70	16.92	10.51		500	8.72	31.39	19.50
	600	4.77	17.17	10.67		600	8.92	32.11	19.95
	700	4.82	17.35	10.75		700	9.08	32.69	20.31
	800	4.85	17.46	10.85		800	9.21	33.16	20.60
	900	4.89	17.60	10.94		900	9.31	33.52	20.83
	1000	4.91	17.68	10.99		1000	9.40	33.84	21.03
	1200	4.95	17.82	11.07		1200	9.53	34.31	21.32
	1500	4.99	17.96	11.16		1500	9.67	34.81	21.63
	2000	5.03	18.11	11.25		2000	9.82	35.35	21.97
	3000	5.08	18.29	11.36		3000	10.09	36.32	22.57
	∞	5.17	18.61	11.56		∞	10.34	37.22	23.13

Latitude 40° (Continued).

$\frac{\Delta B \text{ (mm.)}}{100 \text{ km.}}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}	$\frac{\Delta B \text{ (mm.)}}{100 \text{ km.}}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
$\frac{1.0 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{158 \text{ mi.}}$	100	7.28	26.21	16.29	$\frac{2.5 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{63 \text{ mi.}}$	100	13.34	48.02	29.84
	200	8.80	31.68	19.69		200	16.96	61.06	37.94
	300	9.63	34.67	21.54		300	19.20	69.12	42.95
	400	10.17	36.61	22.75		400	20.79	74.84	46.50
	500	10.55	37.98	23.60		500	21.99	79.16	49.19
	600	10.83	38.99	24.23		600	22.95	82.62	51.34
	700	11.06	39.82	24.74		700	23.73	85.43	53.08
	800	11.24	40.46	25.14		800	24.38	87.77	54.54
	900	11.39	41.00	25.48		900	24.94	89.78	55.79
	1000	11.51	41.44	25 75		1000	25.42	91.51	56.86
	1200	11.71	42.16	26.20		1200	26.20	94.32	58.66
	1500	11.91	42.88	26.64		1500	27.09	97.52	60.60
	2000	12.14	43.70	27.15		2000	28.09	101.12	62.83
	3000	12.38	45.57	28.32		3000	29.26	105.34	65.45
	∞	12.92	46.51	28.90		∞	32.30	116.28	72.25
$\frac{1.5 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{105 \text{ mi.}}$	100	9.60	34.56	21.47	$\frac{3.0 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{53 \text{ mi.}}$	100	14.95	53.82	33.44
	200	11.87	42.73	26.55		200	19.17	69.01	42.88
	300	13.19	47.48	29.50		300	21.83	78.59	48.83
	400	14.09	50.72	31.52		400	23.74	85.46	53.10
	500	14.74	53.06	32.97		500	25.21	90.76	56.40
	600	15.25	54.90	34.11		600	26.39	95.00	59.03
	700	15.65	56.34	35.01		700	27.36	98.50	61.21
	800	15.98	57.53	35.75		800	28.18	101.45	63.04
	900	16.25	58.50	36.35		900	28.88	103.97	64.60
	1000	16.48	59.33	36.87		1000	29.49	106.16	65.96
	1200	16.86	60.70	37.72		1200	30.50	109.80	68.23
	1500	17.26	62.14	38.61		1500	31.65	113.94	70.80
	2000	17.71	63.76	39.62		2000	32.97	118.69	73.75
	3000	18.21	65.56	40.74		3000	34.50	124.20	77.17
	∞	19.38	69.77	43.35		∞	38.77	139.57	86.72
$\frac{2.0 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{79 \text{ mi.}}$	100	11.57	41.65	25.88	$\frac{4.0 \text{ mm.}}{100 \text{ km.}} = \frac{0.1 \text{ in.}}{39 \text{ mi.}}$	100	17.82	64.15	39.86
	200	14.55	52.38	32.55		200	23.14	83.30	51.76
	300	16.35	58.86	36.57		300	26.58	95.69	59.46
	400	17.60	63.36	39.37		400	29.11	104.80	65.12
	500	18.52	66.67	41.43		500	31.08	111.89	69.53
	600	19.26	69.34	43.09		600	32.69	117.68	73.12
	700	19.84	71.42	44.38		700	34.04	122.54	76.14
	800	20.33	73.19	45.48		800	35.18	126.65	78.70
	900	20.74	74.66	46.39		900	36.18	130.25	80.93
	1000	21.10	75.96	47.20		1000	37.05	133.38	82.88
	1200	21.67	78.01	48.47		1200	38.50	138.60	86.12
	1500	22.31	80.32	49.91		1500	40.20	144.72	89.93
	2000	23.02	82.87	51.49		2000	42.19	151.88	94.37
	3000	23.83	85.79	53.31		3000	44.60	160.56	99.86
	∞	25.84	93.02	57.80		∞	51.69	186.08	115.62

Latitude 45°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	1.97	7.09	4.41	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	5.96	21.46	12.87
	200	2.13	7.67	4.77		200	7.01	25.24	15.68
	300	2.19	7.88	4.90		300	7.55	27.18	16.89
	400	2.23	8.03	4.99		400	7.89	28.40	17.42
	500	2.25	8.10	5.03		500	8.12	29.23	18.16
	600	2.27	8.17	5.08		600	8.29	29.84	18.54
	700	2.28	8.21	5.10		700	8.42	30.31	18.83
	800	2.29	8.24	5.12		800	8.52	30.67	19.06
	900	2.29	8.24	5.12		900	8.60	30.96	19.24
	1000	2.30	8.28	5.14		1000	8.67	31.21	19.39
	1200	2.31	8.32	5.17		1200	8.78	31.61	19.64
	1500	2.32	8.35	5.19		1500	8.89	32.00	19.84
	2000	2.33	8.39	5.21		2000	9.01	32.44	20.16
	3000	2.33	8.39	5.21		3000	9.14	32.90	20.44
	∞	2.35	8.46	5.26		∞	9.40	33.84	21.03
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	3.52	12.67	7.87	$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	7.40	26.64	16.55
	200	3.94	14.18	8.81		200	8.36	30.10	18.70
	300	4.14	14.90	9.26		300	9.08	32.69	20.31
	400	4.26	15.34	9.53		400	9.54	34.34	21.34
	500	4.33	15.59	9.69		500	9.86	35.50	22.06
	600	4.39	15.80	9.82		600	10.10	36.36	22.59
	700	4.43	15.95	9.91		700	10.28	37.01	23.00
	800	4.46	16.06	9.98		800	10.43	37.55	23.33
	900	4.49	16.16	10.04		900	10.55	37.98	23.60
	1000	4.50	16.20	10.07		1000	10.65	38.34	23.82
	1200	4.53	16.31	10.13		1200	10.80	38.88	24.16
	1500	4.56	16.42	10.20		1500	10.97	39.49	24.54
	2000	4.60	16.56	10.29		2000	11.15	40.14	24.94
	3000	4.63	16.57	10.36		3000	11.33	40.79	25.35
	∞	4.70	16.92	10.51		∞	11.75	42.30	26.28
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	4.81	17.32	10.76	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	9.28	33.41	20.72
	200	5.55	19.98	12.42		200	11.36	40.90	25.41
	300	5.92	21.31	13.24		300	12.54	45.14	28.05
	400	6.13	22.07	13.71		400	13.32	47.95	29.79
	500	6.28	22.61	14.05		500	13.88	49.97	31.05
	600	6.39	23.00	14.29		600	14.31	51.52	32.01
	700	6.47	23.29	14.47		700	14.65	52.74	32.77
	800	6.53	23.51	14.61		800	14.92	53.71	33.37
	900	6.58	23.69	14.72		900	15.15	54.54	33.89
	1000	6.62	23.83	14.81		1000	15.34	55.22	34.31
	1200	6.69	24.08	14.96		1200	15.64	56.30	34.98
	1500	6.75	24.30	15.10		1500	15.97	57.49	35.72
	2000	6.82	24.55	15.25		2000	16.33	58.79	36.53
	3000	6.90	24.84	15.43		3000	16.72	60.19	37.40
	∞	7.05	25.38	15.77		∞	17.62	63.43	39.41

Latitude 45° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	11.24	40.46	25.14	$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	14.59	52.52	32.63
	200	14.00	50.40	31.32		200	18.55	66.78	41.50
	300	15.61	56.20	34.92		300	21.00	75.60	46.98
	400	16.72	60.19	37.40		400	22.72	81.79	50.82
	500	17.53	63.11	39.21		500	24.04	86.54	53.77
	600	18.16	65.38	40.62		600	25.08	90.29	56.10
	700	18.67	67.21	41.76		700	25.93	93.35	58.00
	800	19.08	68.69	42.68		800	26.64	95.90	59.59
	900	19.43	69.95	43.47		900	27.24	98.06	60.93
	1000	19.72	70.99	44.11		1000	27.77	99.97	62.12
	1200	20.20	72.72	45.23		1200	28.62	103.03	64.02
	1500	20.72	74.59	46.35		1500	29.58	106.49	66.17
	2000	21.30	76.68	46.78		2000	30.68	110.45	68.63
	3000	21.94	78.98	49.08		3000	31.94	114.98	71.45
	∞	23.49	84.56	52.54		∞	35.24	126.86	78.83
$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	12.99	46.76	29.05	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	17.45	62.82	39.03
	200	16.37	58.93	36.62		200	22.48	80.93	50.29
	300	18.41	66.28	41.18		300	25.68	92.45	57.45
	400	19.83	71.37	44.35		400	27.99	100.76	62.61
	500	20.90	75.24	46.75		500	29.78	107.21	66.62
	600	21.74	78.26	48.63		600	31.23	112.43	69.86
	700	22.41	80.68	50.13		700	32.42	116.71	72.52
	800	22.97	82.69	51.38		800	33.44	120.38	74.80
	900	23.44	84.38	52.43		900	34.31	123.52	76.75
	1000	23.85	85.86	53.35		1000	35.06	126.22	78.43
	1200	24.51	88.24	54.83		1200	36.32	130.75	81.25
	1500	25.25	90.90	56.48		1500	37.77	135.97	84.49
	2000	26.07	93.85	58.32		2000	39.45	142.02	88.25
	3000	27.01	97.24	60.42		3000	41.43	149.15	92.68
	∞	29.37	105.73	65.70		∞	46.99	169.16	105.11

Latitude 50°.

$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	1.86	6.70	4.16	$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	3.34	12.02	7.47
	200	1.99	7.16	4.45		200	3.72	13.39	8.32
	300	2.04	7.34	4.56		300	3.89	14.00	8.70
	400	2.07	7.45	4.63		400	3.98	14.33	8.90
	500	2.09	7.52	4.67		500	4.04	14.54	9.04
	600	2.10	7.56	4.70		600	4.09	14.72	9.15
	700	2.11	7.60	4.72		700	4.12	14.83	9.22
	800	2.12	7.63	4.74		800	4.15	14.94	9.28
	900	2.13	7.67	4.77		900	4.17	15.01	9.33
	1000	2.13	7.67	4.77		1000	4.18	15.05	9.35
	1200	2.14	7.70	4.79		1200	4.21	15.16	9.42
	1500	2.14	7.70	4.79		1500	4.23	15.23	9.46
	2000	2.15	7.74	4.81		2000	4.26	15.34	9.53
	3000	2.15	7.74	4.81		3000	4.28	15.41	9.59
	∞	2.17	7.81	4.85		∞	4.34	15.62	9.71

Latitude 50° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	4.61	16.60	10.31	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	9.01	32.44	20.16
	200	5.27	18.97	11.79		200	10.92	39.31	24.43
	300	5.58	20.09	12.48		300	11.98	43.13	26.80
	400	5.76	20.74	12.89		400	12.67	45.61	28.34
	500	5.89	21.20	13.17		500	13.16	47.38	29.44
	600	5.97	21.49	13.35		600	13.53	48.71	30.27
	700	6.04	21.74	13.51		700	13.82	49.75	30.91
	800	6.09	21.92	13.62		800	14.06	50.62	31.45
	900	6.13	22.07	13.71		900	14.25	51.30	31.88
	1000	6.17	22.21	13.80		1000	14.41	51.88	32.24
	1200	6.22	22.39	13.91		1200	14.66	52.78	32.80
	1500	6.27	22.57	14.02		1500	14.93	53.75	33.40
	2000	6.33	22.79	14.16		2000	15.23	54.83	34.07
	3000	6.38	22.97	14.27		3000	15.54	55.94	34.76
	∞	6.51	23.44	14.57		∞	16.26	58.54	36.38
$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	5.73	20.63	12.82	$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	10.95	39.42	24.49
	200	6.68	24.05	14.94		200	13.51	48.64	30.22
	300	7.15	25.74	15.99		300	14.99	53.96	33.53
	400	7.44	26.78	16.64		400	15.98	57.53	35.75
	500	7.63	27.47	17.07		500	16.70	60.12	37.36
	600	7.77	27.97	17.38		600	17.25	62.10	38.59
	700	7.88	28.37	17.63		700	17.69	63.68	39.57
	800	7.97	28.69	17.83		800	18.04	64.94	40.35
	900	8.03	28.91	17.96		900	18.34	66.02	41.02
	1000	8.09	29.12	18.09		1000	18.59	66.92	41.58
	1200	8.18	29.45	18.30		1200	18.99	68.36	42.48
	1500	8.27	29.77	18.50		1500	19.43	69.95	43.47
	2000	8.36	30.10	18.70		2000	19.91	71.68	44.54
	3000	8.46	30.46	18.93		3000	20.44	73.58	45.72
	∞	8.67	31.21	19.39		∞	21.69	78.08	48.52
$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	6.76	24.34	15.12	$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	12.69	45.68	28.38
	200	7.99	28.76	17.87		200	15.86	57.10	35.48
	300	8.63	31.07	19.31		300	17.73	63.83	39.66
	400	9.02	32.47	20.18		400	19.02	68.47	42.55
	500	9.29	33.44	20.78		500	19.97	71.89	44.67
	600	9.50	34.20	21.25		600	20.71	74.56	46.33
	700	9.65	34.74	21.59		700	21.30	76.68	47.65
	800	9.77	35.17	21.85		800	21.79	78.44	48.74
	900	9.87	35.53	22.08		900	22.21	79.96	49.68
	1000	9.96	35.86	22.28		1000	22.55	81.18	50.44
	1200	10.09	36.32	22.57		1200	23.12	83.23	51.72
	1500	10.22	36.79	22.86		1500	23.74	85.46	53.10
	2000	10.36	37.30	23.18		2000	24.47	88.09	54.74
	3000	10.52	37.87	23.53		3000	25.21	90.76	56.40
	∞	10.84	39.02	24.25		∞	27.11	97.60	60.65

Latitude 50° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	14.28	51.41	31.95	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	17.12	61.63	38.29
	200	18.01	64.84	40.29		200	21.90	78.84	48.99
	300	20.27	72.97	45.34		300	24.89	89.60	55.67
	400	21.85	78.66	48.88		400	27.03	97.31	60.47
	500	23.03	82.91	51.52		500	28.66	103.18	64.11
	600	23.96	86.26	53.60		600	29.97	107.89	67.04
	700	24.72	88.99	55.30		700	31.04	111.74	69.43
	800	25.34	91.22	56.68		800	31.95	115.02	71.47
	900	25.87	93.13	57.87		900	32.72	117.79	73.19
	1000	26.33	94.79	58.90		1000	33.39	120.20	74.69
	1200	27.07	97.45	60.55		1200	34.50	124.20	77.17
	1500	27.89	100.40	62.39		1500	35.75	128.70	79.97
	2000	28.81	103.72	64.45		2000	37.19	133.88	83.19
	3000	29.86	107.50	66.80		3000	38.87	139.93	86.95
	∞	32.53	117.11	72.77		∞	43.37	156.13	97.01

Latitude 55°.

$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	1.77	6.37	3.96	$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	4.44	15.98	9.93
	200	1.88	6.77	4.21		200	5.03	18.11	11.25
	300	1.93	6.95	4.32		300	5.30	19.08	11.86
	400	1.95	7.02	4.36		400	5.46	19.66	12.22
	500	1.96	7.06	4.39		500	5.57	20.05	12.46
	600	1.97	7.09	4.41		600	5.64	20.30	12.61
	700	1.98	7.13	4.43		700	5.70	20.52	12.75
	800	1.99	7.16	4.45		800	5.74	20.66	12.84
	900	1.99	7.16	4.45		900	5.77	20.77	12.91
	1000	1.99	7.16	4.45		1000	5.80	20.88	12.97
	1200	2.00	7.20	4.47		1200	5.85	21.06	13.09
	1500	2.00	7.20	4.47		1500	5.89	21.20	13.17
	2000	2.01	7.24	4.50		2000	5.94	21.38	13.29
	3000	2.02	7.27	4.52		3000	5.99	21.56	13.40
	∞	2.03	7.31	4.54		∞	6.08	21.89	13.60
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	3.20	11.52	7.16	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	5.54	19.94	12.39
	200	3.53	12.71	7.90		200	6.40	23.04	14.32
	300	3.68	13.25	8.23		300	6.82	24.55	15.25
	400	3.76	13.54	8.41		400	7.07	25.45	15.81
	500	3.81	13.72	8.53		500	7.24	26.06	16.19
	600	3.85	13.86	8.61		600	7.36	26.50	16.47
	700	3.88	13.97	8.68		700	7.45	26.82	16.67
	800	3.90	14.04	8.72		800	7.52	27.07	16.82
	900	3.91	14.08	8.75		900	7.58	27.29	16.96
	1000	3.93	14.15	8.79		1000	7.63	27.47	17.07
	1200	3.95	14.22	8.84		1200	7.70	27.72	17.22
	1500	3.97	14.29	8.88		1500	7.77	27.97	17.38
	2000	3.99	14.36	8.92		2000	7.85	38.26	17.56
	3000	4.01	14.44	8.97		3000	7.94	28.58	17.76
	∞	4.06	14.62	9.08		∞	8.11	29.20	18.14

Latitude 55° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	6.55	23.58	14.65	$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	12.43	44.75	27.81
	200	7.68	27.65	17.18		200	15.41	55.48	34.47
	300	8.24	29.66	18.43		300	17.15	61.74	38.36
	400	8.59	30.92	19.21		400	18.22	65.59	40.76
	500	8.83	31.79	19.75		500	19.19	69.08	42.92
	600	9.01	32.44	20.16		600	19.85	71.46	44.40
	700	9.14	32.90	20.44		700	20.38	73.37	45.59
	800	9.25	33.30	20.69		800	20.82	74.95	46.57
	900	9.33	33.59	20.87		900	21.18	76.25	47.38
	1000	9.40	33.84	21.03		1000	21.49	77.36	48.07
	1200	9.51	34.24	21.28		1200	21.98	79.13	49.17
	1500	9.63	34.67	21.54		1500	22.52	81.07	50.37
	2000	9.74	35.06	21.79		2000	23.12	83.23	51.72
	3000	9.87	35.53	22.08		3000	23.77	85.57	53.17
	∞	10.14	36.50	22.68		∞	25.35	91.26	56.71
$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	8.77	31.57	19.62	$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	14.00	50.40	31.32
	200	10.55	37.98	23.60		200	17.54	63.14	39.23
	300	11.51	41.44	25.75		300	19.65	70.74	43.96
	400	12.13	43.67	27.14		400	21.00	75.60	46.98
	500	12.56	45.22	28.10		500	22.18	79.85	49.62
	600	12.89	46.40	28.83		600	23.03	82.91	51.52
	700	13.14	47.30	29.39		700	23.70	85.32	53.02
	800	13.35	48.06	29.86		800	24.26	87.34	54.27
	900	13.51	48.64	30.22		900	24.73	89.03	55.32
	1000	13.65	49.14	30.53		1000	25.13	90.47	56.22
	1200	13.87	49.93	31.03		1200	25.79	92.84	57.69
	1500	14.10	50.76	31.56		1500	26.50	95.40	59.28
	2000	14.35	51.66	32.10		2000	27.30	98.28	61.07
	3000	14.62	52.63	32.70		3000	28.20	101.52	63.08
	∞	15.21	54.76	34.03		∞	30.42	109.51	68.05
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	10.70	38.52	23.94	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	16.84	60.62	37.67
	200	13.10	47.16	29.30		200	21.40	77.04	47.87
	300	14.45	52.02	32.32		300	24.21	87.16	54.16
	400	15.35	55.26	34.34		400	26.10	93.96	58.38
	500	16.00	57.60	35.79		500	27.70	99.72	61.96
	600	16.48	59.33	36.87		600	28.91	104.08	64.67
	700	16.88	60.77	37.76		700	29.88	107.57	66.84
	800	17.19	61.88	38.45		800	30.70	110.52	68.67
	900	17.45	62.82	39.03		900	31.39	113.00	70.22
	1000	17.67	63.61	39.53		1000	31.99	115.16	71.56
	1200	18.02	64.87	40.31		1200	32.95	118.62	73.70
	1500	18.39	66.20	41.14		1500	34.08	122.69	76.24
	2000	18.80	67.68	42.05		2000	35.34	127.22	79.05
	3000	19.25	69.30	43.06		3000	36.79	132.44	82.29
	∞	20.28	73.01	45.37		∞	40.56	146.02	90.73

Latitude 60°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	100	1.69	6.08	3.78	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	100	5.38	19.37	12.04
	200	1.79	6.44	4.00		200	6.17	22.21	13.80
	300	1.83	6.59	4.10		300	6.54	23.54	14.63
	400	1.85	6.66	4.14		400	6.77	24.37	15.14
	500	1.86	6.70	4.16		500	6.92	24.91	15.48
	600	1.87	6.73	4.18		600	7.02	25.27	15.70
	700	1.88	6.77	4.21		700	7.10	25.56	15.88
	800	1.88	6.77	4.21		800	7.17	25.81	16.04
	900	1.89	6.80	4.23		900	7.22	25.99	16.15
	1000	1.89	6.80	4.23		1000	7.26	26.14	16.24
	1200	1.90	6.84	4.25		1200	7.32	26.35	16.37
	1500	1.90	6.84	4.25		1500	7.38	26.57	16.51
	2000	1.90	6.84	4.25		2000	7.45	26.82	16.67
	3000	1.91	6.88	4.28		3000	7.53	27.11	16.85
	∞	1.91	6.88	4.28		∞	7.60	27.36	17.00
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	100	3.08	11.09	6.89	$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	100	6.37	22.93	14.25
	200	3.38	12.17	7.56		200	7.42	26.71	16.60
	300	3.51	12.64	7.85		300	7.93	28.55	17.74
	400	3.58	12.89	8.01		400	8.25	29.70	18.45
	500	3.63	13.07	8.12		500	8.46	30.46	18.92
	600	3.66	13.18	8.19		600	8.61	31.00	19.26
	700	3.68	13.25	8.23		700	8.73	31.43	19.53
	800	3.70	13.32	8.28		800	8.82	31.75	19.73
	900	3.72	13.39	8.32		900	8.90	32.04	19.91
	1000	3.73	13.43	8.34		1000	8.96	32.26	20.05
	1200	3.74	13.46	8.36		1200	9.05	32.58	20.24
	1500	3.76	13.54	8.41		1500	9.15	32.94	20.47
	2000	3.78	13.61	8.46		2000	9.25	33.30	20.69
	3000	3.80	13.68	8.50		3000	9.37	33.73	20.96
	∞	3.80	13.68	8.50		∞	9.50	34.20	21.25
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	100	4.29	15.44	9.59	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	100	8.57	30.85	19.17
	200	4.83	17.39	10.81		200	10.24	36.86	22.90
	300	5.07	18.25	11.34		300	11.12	40.03	24.87
	400	5.22	18.79	11.68		400	11.68	42.05	26.13
	500	5.31	19.12	11.88		500	12.08	43.49	27.02
	600	5.37	19.33	12.04		600	12.37	44.53	27.67
	700	5.42	19.51	12.12		700	12.59	45.32	28.16
	800	5.46	19.66	12.22		800	12.77	45.97	28.56
	900	5.49	19.76	12.28		900	12.92	46.51	28.90
	1000	5.51	19.84	12.33		1000	13.05	46.98	29.19
	1200	5.55	19.98	12.42		1200	13.23	47.63	29.60
	1500	5.59	20.12	12.50		1500	13.44	48.38	30.06
	2000	5.63	20.27	12.59		2000	13.65	49.14	30.53
	3000	5.67	20.41	12.68		3000	13.88	49.97	31.05
	∞	5.70	20.52	12.85		∞	14.25	51.30	31.88

Latitude 60° (Continued).

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	100	10.48	37.73	23.44	$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	100	14.77	53.17	33.04
	200	12.75	45.90	28.52		200	17.14	61.70	38.34
	300	14.01	50.44	31.34		300	19.12	68.83	42.77
	400	14.83	53.39	33.17		400	20.48	73.73	45.81
	500	15.42	55.51	34.49		500	21.47	77.29	48.03
	600	15.86	57.10	35.48		600	22.24	80.06	49.75
	700	16.21	58.36	36.26		700	22.86	82.30	51.14
	800	16.49	59.36	36.88		800	23.36	84.10	52.26
	900	16.72	60.19	37.40		900	23.79	85.64	53.22
	1000	16.92	60.91	37.85		1000	24.15	86.94	54.02
	1200	17.22	61.99	38.52		1200	24.73	89.03	55.32
	1500	17.56	63.22	39.28		1500	25.38	91.37	56.77
	2000	17.92	64.51	40.08		2000	26.08	93.89	58.34
	3000	18.30	65.88	40.94		3000	26.87	96.73	60.10
	∞	18.99	68.36	42.48		∞	28.49	102.56	63.73
$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	100	12.20	43.92	27.29	$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	100	16.59	59.72	37.11
	200	15.03	54.11	33.62		200	20.96	75.46	46.89
	300	16.66	59.98	37.27		300	23.63	85.07	52.86
	400	17.75	63.90	39.71		400	25.00	91.80	57.04
	500	18.54	66.74	41.47		500	26.90	96.84	60.17
	600	19.14	68.90	42.81		600	28.01	100.84	62.66
	700	19.62	70.63	43.89		700	28.91	104.08	64.67
	800	20.01	72.04	44.76		800	29.66	106.78	66.35
	900	20.34	73.22	45.50		900	30.29	109.04	67.76
	1000	20.61	74.20	46.10		1000	30.84	111.02	68.98
	1200	21.05	75.78	47.09		1200	31.73	114.23	70.98
	1500	21.53	77.51	48.16		1500	32.72	117.79	73.19
	2000	22.05	79.38	49.32		2000	33.83	121.79	75.68
	3000	22.63	81.47	50.62		3000	35.11	126.40	78.54
	∞	23.74	85.46	53.10		∞	37.98	136.73	84.96

TABLE II.

Gradient Wind Velocity for Anticyclonic Movement.

Latitude 25°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$	$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	255.1	7.86	28.30	17.59	$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	1020.4	31.44	113.18	70.33
	300	5.67	20.41	12.68		1200	22.67	81.61	50.71
	400	4.91	17.68	10.99		1500	20.09	72.32	44.94
	500	4.63	16.67	10.36		2000	18.50	66.60	41.38
	600	4.47	16.09	10.00		3000	17.35	62.46	38.81
	700	4.38	15.77	9.80		∞	15.72	56.59	35.16
	800	4.31	15.52	9.64					
	900	4.26	15.34	9.53					
	1000	4.22	15.19	9.44					
	1200	4.17	15.01	9.33	$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	1275.5	39.30	141.48	87.91
	1500	4.11	14.78	9.18		1500	28.34	102.02	63.39
	2000	4.07	14.65	9.10		2000	24.54	88.34	54.89
	3000	4.02	14.47	8.99		3000	22.36	80.50	50.02
	∞	3.93	14.15	8.79		∞	19.65	70.74	43.96
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	510.2	15.72	56.59	35.16	$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	1913.3	58.96	212.26	131.89
	600	11.34	40.82	25.36		2000	48.80	175.68	109.16
	700	10.34	37.22	23.13		3000	36.81	132.52	82.34
	800	9.82	35.35	21.97		∞	29.48	106.13	65.95
	900	9.48	34.13	21.21					
	1000	9.25	33.30	20.69					
	1200	8.94	32.18	20.00					
	1500	8.68	31.25	19.42					
	2000	8.44	30.38	18.88	$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	2551	78.62	283.03	175.87
	3000	8.23	29.63	18.41		3000	56.68	204.05	126.79
	∞	7.86	28.30	17.58		∞	39.31	141.52	87.94
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	765.3	23.58	84.89	52.75					
	800	19.52	70.27	43.66					
	900	17.01	61.24	38.05					
	1000	15.89	57.20	35.54					
	1200	14.72	52.99	32.93					
	1500	13.87	49.93	31.03					
	2000	13.21	47.56	29.55					
	3000	12.66	45.58	28.32					
	∞	11.79	42.44	26.37					

Latitude 30°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	182.25	6.64	23.90	14.85
	200	5.12	18.43	11.45
	300	4.08	14.69	9.13
	400	3.82	13.75	8.54
	500	3.70	13.32	8.28
	600	3.62	13.03	8.10
	700	3.57	12.85	7.98
	800	3.54	12.74	7.92
	900	3.51	12.64	7.85
	1000	3.49	12.56	7.80
	1200	3.46	12.46	7.74
	1500	3.43	12.35	7.67
	2000	3.40	12.24	7.61
	3000	3.38	12.17	7.56
	∞	3.32	11.95	7.43
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	364.5	13.28	47.81	29.71
	400	10.24	36.86	22.90
	500	8.74	31.46	19.55
	600	8.17	29.41	18.27
	700	7.85	28.26	17.56
	800	7.65	27.54	17.11
	900	7.50	27.00	16.78
	1000	7.40	26.64	16.55
	1200	7.24	26.06	16.19
	1500	7.11	25.60	15.91
	2000	6.98	25.13	15.62
	3000	6.86	24.70	15.35
	∞	6.64	23.90	14.85
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	546.75	19.94	71.78	44.60
	600	15.36	55.30	34.36
	700	13.58	48.89	30.38
	800	12.76	45.94	28.55
	900	12.26	44.14	27.43
	1000	11.91	42.88	26.64
	1200	11.49	41.36	25.70
	1500	11.09	39.92	24.81
	2000	10.76	38.74	24.07
	3000	10.47	37.69	23.42
	∞	9.97	35.89	22.30
$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	729	26.58	95.69	59.46
	800	20.48	73.73	45.81
	900	18.51	66.64	41.41
	1000	17.48	62.93	39.10
	1200	16.34	58.82	36.55
	1500	15.48	55.73	34.63
	2000	14.79	53.24	33.08
	3000	14.21	51.16	31.79
	∞	13.29	47.84	29.73
$\frac{1.0\ mm.}{100\ km.} = \frac{0.1\ in.}{158\ mi.}$	911.25	33.22	119.59	74.31
	1000	25.60	92.16	57.26
	1200	22.29	80.24	49.86
	1500	20.43	73.55	45.70
	2000	19.12	68.83	42.77
	3000	18.11	65.20	40.51
	∞	16.61	59.80	37.16
$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	1367.9	48.84	179.42	111.49
	1500	38.40	138.24	85.90
	2000	31.89	114.80	71.33
	3000	28.68	103.25	64.16
	∞	24.92	89.71	55.74
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	1822.5	66.44	239.18	148.62
	2000	51.20	184.32	114.53
	3000	40.85	147.06	95.76
	∞	33.22	119.59	74.31
$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	2278.1	83.06	299.02	185.80
	3000	55.72	200.59	124.64
	∞	41.53	149.51	92.90
$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	2733.8	99.68	358.85	222.98
	3000	76.79	276.44	171.77
	∞	49.84	179.42	111.49

Latitude 35°.

ΔB (*mm.*) / 100 *km.*	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
0.2 *mm.* =	138.5	5.80	20.88	12.88
100 *km.*	200	3.73	13.43	8.35
0.1 *in.*	300	3.34	12.02	7.47
789 *mi.*	400	3.20	11.52	7.16
	500	3.13	11.27	7.00
	600	3.09	11.12	6.91
	700	3.06	11.02	6.85
	800	3.03	10.91	6.78
	900	3.02	10.87	6.75
	1000	3.00	10.80	6.71
	1200	2.98	10.73	6.67
	1500	2.97	10.69	6.64
	2000	2.95	10.62	6.60
	3000	2.93	10.55	6.56
	∞	2.90	10.44	6.49
0.4 *mm.* =	277.0	11.58	41.69	25.90
100 *km.*	300	9.07	32.65	20.30
0.1 *in.*	400	7.46	26.86	16.61
395 *mi.*	500	6.95	25.02	15.55
	600	6.68	24.05	14.94
	700	6.52	23.47	14.58
	800	6.41	23.08	14.34
	900	6.32	22.75	14.14
	1000	6.26	22.54	14.01
	1200	6.17	22.21	13.80
	1500	6.09	21.92	13.62
	2000	6.01	21.64	13.45
	3000	5.93	21.35	13.27
	∞	5.79	20.84	12.95
0.6 *mm.* =	415.5	17.38	62.57	38.88
100 *km.*	500	12.31	44.32	27.54
0.1 *in.*	600	11.18	40.25	25.01
263 *mi.*	700	10.61	38.20	23.74
	800	10.26	36.94	22.95
	900	10.02	36.07	22.41
	1000	9.85	35.46	22.03
	1200	9.61	34.60	21.50
	1500	9.39	33.80	21.00
	2000	9.19	33.08	20.56
	3000	9.01	32.44	20.16
	∞	8.69	31.28	19.48
0.8 *mm.* =	554.0	23.16	83.38	51.81
100 *km.*	600	18.14	65.30	40.58
0.1 *in.*	700	15.91	57.28	35.59
197 *mi.*	800	14.90	53.64	33.33
	900	14.30	51.48	31.99
	1000	13.89	50.00	31.07
	1200	13.36	48.10	29.89

ΔB (*mm.*) / 100 *km.*	r	V^{m}_{s}	V^{km}_{hr}	V^{mi}_{hr}
0.8 *mm.* =	1500	12.92	46.51	28.90
100 *km.*	2000	12.52	45.07	28.01
0.1 *in.*	3000	12.17	43.81	27.22
197 *mi.*	∞	11.58	41.69	25.90
1.0 *mm.* =	692.5	28.96	104.26	64.78
100 *km.*	700	26.24	94.46	58.70
0.1 *in.*	800	21.19	76.28	47.40
158 *mi.*	900	19.57	70.45	43.78
	1000	18.63	67.07	41.68
	1200	17.55	63.18	39.26
	1500	16.71	60.16	37.38
	2000	16.01	57.64	35.82
	3000	15.43	55.55	34.52
	∞	14.48	52.13	32.39
1.5 *mm.* =	1038.7	43.44	156.38	97.15
100 *km.*	1200	31.79	114.44	71.11
0.1 *in.*	1500	27.95	100.62	62.52
105 *mi.*	2000	25.66	92.38	57.40
	3000	24.02	86.47	53.73
	∞	21.72	78.19	48.58
2.0 *mm.* =	1385.0	57.92	208.51	129.56
100 *km.*	1500	45.36	163.30	101.47
0.1 *in.*	2000	37.26	134.14	83.33
79 *mi.*	3000	33.41	120.28	74.70
	∞	28.96	104.26	64.78
2.5 *mm.* =	1731.2	72.40	260.64	161.95
100 *km.*	2000	52.98	190.73	118.51
0.1 *in.*	3000	43.87	157.93	98.13
63 *mi.*	∞	36.20	130.32	80.98
3.0 *mm.* =	2077.5	86.88	312.77	194.35
100 *km.*	3000	55.89	201.20	125.02
0.1 *in.*	∞	43.44	156.38	97.17
53 *mi.*				
4.0 *mm.* =	2770.0	115.84	417.02	259.12
100 *km.*	3000	90.72	326.59	202.93
0.1 *in.*	∞	57.92	208.51	129.56
39 *mi.*				

Latitude 40°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{0.2\ mm.}{100\ km.} = \frac{0.1\ in.}{789\ mi.}$	110.25	5.16	18.58	11.55
	200	3.10	11.16	6.93
	300	2.88	10.37	6.44
	400	2.79	10.04	6.24
	500	2.74	9.86	6.13
	600	2.72	9.79	6.08
	700	2.70	9.72	6.04
	800	2.68	9.65	6.00
	900	2.67	9.61	5.97
	1000	2.66	9.58	5.95
	1200	2.65	9.54	5.93
	1500	2.63	9.47	5.88
	2000	2.62	9.43	5.86
	3000	2.61	9.40	5.84
	∞	2.58	9.29	5.77
$\frac{0.4\ mm.}{100\ km.} = \frac{0.1\ in.}{395\ mi.}$	220.5	10.34	37.22	23.13
	300	6.83	24.59	15.28
	400	6.19	22.28	13.84
	500	5.92	21.31	13.24
	600	5.76	20.74	12.89
	700	5.66	20.38	12.66
	800	5.59	20.12	12.50
	900	5.53	19.91	12.37
	1000	5.49	19.76	12.28
	1200	5.43	19.55	12.15
	1500	5.37	19.33	12.01
	2000	5.32	19.15	11.90
	3000	5.27	18.97	11.79
	∞	5.17	18.61	11.56
$\frac{0.6\ mm.}{100\ km.} = \frac{0.1\ in.}{263\ mi.}$	330.75	15.50	55.80	34.67
	400	10.95	39.42	24.50
	500	9.80	35.28	21.92
	600	9.29	33.44	20.78
	700	8.98	32.33	20.09
	800	8.78	31.61	19.64
	900	8.64	31.10	19.32
	1000	8.53	30.71	19.08
	1200	8.38	30.17	18.79
	1500	8.23	29.63	18.41
	2000	8.10	29.16	18.12
	3000	7.98	28.73	17.85
	∞	7.75	27.90	17.34
$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	441.0	20.68	74.45	46.26
	500	15.39	55.40	34.42
	600	13.65	49.14	30.53
	700	12.86	46.30	28.77
	800	12.38	44.57	27.69
	900	12.06	43.42	26.98
	1000	11.83	42.59	26.46

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
$\frac{0.8\ mm.}{100\ km.} = \frac{0.1\ in.}{197\ mi.}$	1200	11.52	41.47	25.77
	1500	11.24	40.46	25.14
	2000	10.98	39.53	24.56
	3000	10.75	58.70	24.05
	∞	10.34	37.22	23.13
$\frac{1.0\ mm.}{100\ km.} = \frac{1.0\ in.}{158\ mi.}$	551.25	25.84	93.02	57.80
	600	20.12	72.43	45.01
	700	17.69	63.68	39.57
	800	16.59	59.72	37.11
	900	15.93	57.35	35.64
	1000	15.48	55.73	34.63
	1200	14.89	53.60	33.31
	1500	14.39	51.80	32.19
	2000	13.96	50.26	31.23
	3000	13.58	48.89	30.38
	∞	12.92	46.51	28.90
$\frac{1.5\ mm.}{100\ km.} = \frac{0.1\ in.}{105\ mi.}$	826.9	38.76	139.54	86.71
	900	30.18	108.65	67.51
	1000	27.38	98.57	61.25
	1200	24.89	89.60	55.68
	1500	23.22	83.59	51.94
	2000	21.95	79.02	49.10
	3000	20.94	75.38	46.84
	∞	19.38	69.77	43.35
$\frac{2.0\ mm.}{100\ km.} = \frac{0.1\ in.}{79\ mi.}$	1102.5	51.68	186.05	115.61
	1200	40.23	144.83	89.99
	1500	34.13	122.87	76.35
	2000	30.96	111.46	69.26
	3000	29.77	107.17	66.59
	∞	25.84	93.02	57.80
$\frac{2.5\ mm.}{100\ km.} = \frac{0.1\ in.}{63\ mi.}$	1378.1	64.60	232.56	144.50
	1500	50.29	181.04	112.50
	2000	41.48	149.33	92.79
	3000	37.23	134.03	83.28
	∞	32.30	116.28	72.25
$\frac{3.0\ mm.}{100\ km.} = \frac{0.1\ in.}{53\ mi.}$	1653.75	77.54	279.14	173.45
	2000	54.76	197.14	122.50
	3000	46.43	167.15	103.86
	∞	38.77	139.57	86.72
$\frac{4.0\ mm.}{100\ km.} = \frac{0.1\ in.}{39\ mi.}$	2205.0	103.38	372.17	231.25
	3000	68.25	245.70	152.67
	∞	51.69	186.08	115.62

Latitude 45°.

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
0.2 *mm.* =	91.33	4.70	16.92	10.51
100 *km.*	100	3.62	13.03	8.10
0.1 *in.*	200	2.70	9.72	6.04
789 *mi.*	300	2.56	9.22	5.73
	400	2.50	9.00	5.59
	500	2.47	8.89	5.52
	600	2.45	8.82	5.48
	700	2.43	8.75	5.44
	800	2.42	8.71	5.41
	900	2.41	8.68	5.39
	1000	2.41	8.68	5.39
	1200	2.40	8.64	5.37
	1500	2.39	8.60	5.34
	2000	2.38	8.57	5.33
	3000	2.36	8.50	5.28
	∞	2.35	8.46	5.26
0.4 *mm.* =	182.66	9.40	33.84	21.03
100 *km.*	200	7.24	26.06	16.19
0.1 *in.*	300	5.78	20.81	12.93
395 *mi.*	400	5.41	19.48	12.10
	500	5.23	18.83	11.70
	600	5.12	18.43	11.45
	700	5.05	18.18	11.30
	800	5.00	18.00	11.18
	900	4.97	17.89	11.12
	1000	4.94	17.78	11.05
	1200	4.89	17.60	10.94
	1500	4.85	17.46	10.85
	2000	4.81	17.32	10.76
	3000	4.77	17.17	10.67
	∞	4.70	16.92	10.51
0.6 *mm.* =	274.0	14.10	50.76	31.54
100 *km.*	300	10.86	39.10	24.30
0.1 *in.*	400	9.02	32.47	20.18
263 *mi.*	500	8.43	30.35	18.86
	600	8.11	29.20	18.14
	700	7.92	28.51	17.72
	800	7.78	28.01	17.40
	900	7.69	27.68	17.20
	1000	7.61	27.40	17.03
	1200	7.50	27.00	16.78
	1500	7.40	26.64	16.55
	2000	7.31	26.32	16.35
	3000	7.21	25.96	16.13
	∞	7.05	25.38	15.77

$\frac{\Delta B\ (mm.)}{100\ km.}$	r	$V\frac{m}{s}$	$V\frac{km}{hr}$	$V\frac{mi}{hr}$
0.8 *mm.* =	365.33	18.80	67.68	42.05
100 *km.*	400	14.48	52.13	32.39
0.1 *in.*	500	12.36	44.50	27.65
197 *mi.*	600	11.55	41.58	25.84
	700	11.11	40.00	24.85
	800	10.82	38.95	24.20
	900	10.61	38.20	23.74
	1000	10.46	37.66	23.40
	1200	10.25	36.90	22.93
	1500	10.05	36.18	22.48
	2000	9.87	35.53	22.08
	3000	9.70	34.92	21.70
	∞	9.40	33.84	21.03
1.0 *mm.* =	456.66	23.50	84.60	52.57
100 *km.*	500	18.10	65.16	40.49
0.1 *in.*	600	15.76	56.74	35.26
158 *mi.*	700	14.77	53.17	33.04
	800	14.19	51.08	31.74
	900	13.80	49.68	30.87
	1000	13.52	48.67	30.24
	1200	13.14	47.30	29.39
	1500	12.81	46.12	28.66
	2000	12.50	45.00	27.96
	3000	12.23	44.03	27.36
	∞	11.75	42.30	26.28
1.5 *mm.* =	685.0	35.24	126.86	78.83
100 *km.*	700	30.54	109.94	68.31
0.1 *in.*	800	25.50	91.80	57.04
105 *mi.*	900	23.64	85.10	52.88
	1000	22.55	81.18	50.44
	1200	21.28	76.61	47.60
	1500	20.28	73.01	45.37
	2000	19.45	70.02	43.51
	3000	18.76	67.54	41.97
	∞	17.62	63.43	39.41
2.0 *mm.* =	913.33	46.98	169.13	105.09
100 *km.*	1000	36.20	130.32	80.98
0.1 *in.*	1200	31.52	113.47	70.51
79 *mi.*	1500	28.89	104.00	64.62
	2000	27.04	97.34	60.48
	3000	25.61	92.20	57.29
	∞	23.49	84.56	52.54
2.5 *mm.* =	1141.66	58.74	211.46	131.39
100 *km.*	1200	47.93	172.55	107.22
0.1 *in.*	1500	39.40	141.84	88.14
63 *mi.*	2000	35.46	127.66	79.32
	3000	32.86	118.30	73.51
	∞	29.37	105.73	65.70

Latitude 45° (Continued).

ΔB (mm.) / 100 km.	r	V^m_s	V^{km}_{hr}	V^{mi}_{hr}	ΔB (mm.) / 100 km.	r	V^m_s	V^{km}_{hr}	V^{mi}_{hr}
3.0 mm. =	1370.0	70.48	253.73	157.66	4.0 mm. =	1826.66	93.98	338.33	210.23
100 km.	1500	54.30	195.48	121.46	100 km.	2000	72.40	260.64	165.53
0.1 in.	2000	45.10	162.36	100.89	0.1 in.	3000	57.77	207.97	129.23
53 mi.	3000	40.56	146.02	90.73	39. mi.	∞	46.99	169.16	105.11
	∞	35.24	126.86	78.83					

Latitude 50°.

0.2 mm. =	77.66	4.34	15.62	9.71	0.6 mm.	1500	6.78	24.41	15.17
100 km.	100	2.94	10.58	6.57	100 km.	2000	6.71	24.16	15.01
0.1 in.	200	2.43	8.75	5.44	0.1 in.	3000	6.64	23.90	14.85
789 mi.	300	2.33	8.39	5.21	263 mi.	∞	6.51	23.44	14.57
	400	2.29	8.24	5.12					
	500	2.26	8.14	5.06	0.8 mm. =	310.66	17.34	62.42	38.79
	600	2.24	8.06	5.01	100 km.	400	11.78	42.41	26.35
	700	2.23	8.03	4.99	0.1 in.	500	10.74	38.66	24.04
	800	2.23	8.03	4.99	197 mi.	600	10.24	36.86	22.90
	900	2.22	7.99	4.96		700	9.94	35.78	22.23
	1000	2.21	7.96	4.95		800	9.74	35.06	21.79
	1200	2.21	7.96	4.95		900	9.59	34.52	21.45
	1500	2.20	7.92	4.92		1000	9.48	34.13	21.21
	2000	2.19	7.88	4.90		1200	9.31	33.52	20.83
	3000	2.19	7.88	4.90		1500	9.18	33.05	20.54
	∞	2.17	7.81	4.85		2000	9.04	32.54	20.22
						3000	8.91	32.08	19.93
						∞	8.67	31.21	19.39
0.4 mm. =	155.33	8.68	31.25	19.42					
100 km.	200	5.89	21.20	13.17	1.0 mm. =	388.33	21.68	78.05	48.50
0.1 in.	300	5.12	18.43	11.45	100 km.	400	18.51	66.64	41.41
395 mi.	400	4.87	17.53	10.89	0.1 in.	500	14.72	52.99	32.93
	500	4.74	17.06	10.60	158 mi.	600	13.60	48.96	30.42
	600	4.66	16.78	10.43		700	13.01	46.84	29.11
	700	4.61	16.60	10.31		800	12.63	45.47	28.25
	800	4.57	16.45	10.22		900	12.36	44.50	27.65
	900	4.54	16.34	10.15		1000	12.17	43.81	27.22
	1000	4.52	16.27	10.11		1200	11.90	42.84	26.62
	1200	4.49	16.16	10.04		1500	11.65	41.94	26.06
	1500	4.46	16.06	9.98		2000	11.43	41.15	25.57
	2000	4.42	15.91	9.89		3000	11.24	40.46	25.14
	3000	4.40	15.84	9.84		∞	10.84	39.02	24.25
	∞	4.34	15.62	9.71					
					1.5 mm. =	582.5	32.52	117.07	72.75
0.6 mm. =	233.0	13.02	46.87	29.12	100 km.	600	27.76	99.94	62.10
100 km.	300	8.83	31.79	19.75	0.1 in.	700	23.07	83.05	51.60
0.1 in.	400	7.90	28.44	17.67	105 mi.	800	21.38	76.97	47.83
263 mi.	500	7.52	27.07	16.82		900	20.41	73.48	45.66
	600	7.30	26.28	16.33		1000	19.76	71.14	44.20
	700	7.16	25.78	16.02		1200	18.94	68.18	42.36
	800	7.06	25.42	15.80		1500	18.25	65.70	40.82
	900	6.99	25.16	15.63		2000	17.66	63.58	39.51
	1000	6.94	24.98	15.52		3000	17.14	61.70	38.34
	1200	6.86	24.70	15.35		∞	16.26	58.54	36.38

Latitude 50° (Continued).

$\frac{\Delta B \text{ (mm.)}}{100 \text{ km.}}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}	$\frac{\Delta B \text{ (mm.)}}{100 \text{ km.}}$	r	V_s^m	V_{hr}^{km}	V_{hr}^{mi}
2.0 mm. = 100 km. = 0.1 in. = 79 mi.	776.66	43.38	156.17	97.04	3.0 mm. = 100 km. = 0.1 in. = 53 mi	1165.0	65.06	234.22	145.54
	800	37.02	133.27	82.81		1200	55.53	199.91	124.22
	900	31.65	113.94	70.80		1500	44.17	159.01	98.80
	1000	29.45	106.02	65.88		2000	39.52	142.27	88.40
	1200	27.21	97.96	60.87		3000	36.51	131.44	81.67
	1500	25.60	92.16	57.27		∞	32.53	117.11	72.77
	2000	24.34	87.62	54.44					
	3000	23.31	83.92	52.15	4.0 mm. = 100 km. = 0.1 in. = 39 mi.	1553.33	86.74	312.26	194.03
	∞	21.69	78.08	48.52		2000	58.90	212.04	131.75
2.5 mm. = 100 km. = 0.1 in. = 63 mi.	970.8	54.22	195.19	121.29		3000	51.19	184.28	114.51
	1000	46.27	166.57	103.50		∞	43.37	156.13	97.01
	1200	37.72	135.79	84.38					
	1500	34.05	122.58	76.17					
	2000	31.57	113.65	70.62					
	3000	29.75	107.10	66.55					
	∞	27.11	97.60	60.65					

Latitude 55°.

0.2 mm. = 100 km. = 0.1 in. = 789 mi.	67.9	4.06	14.62	9.08	0.6 mm. = 100 km. = 0.1 in. = 263 mi.	203.7	12.16	43.78	27.20
	100	2.59	9.32	5.79		300	7.77	27.97	17.38
	200	2.24	8.06	5.01		400	7.16	25.78	16.02
	300	2.16	7.78	4.83		500	6.88	24.77	15.39
	400	2.12	7.63	4.74		600	6.71	24.16	15.01
	500	2.10	7.56	4.70		700	6.61	23.80	14.79
	600	2.09	7.52	4.67		800	6.53	23.51	14.61
	700	2.08	7.49	4.65		900	6.48	23.33	14.50
	800	2.07	7.45	4.63		1000	6.43	23.15	14.38
	900	2.07	7.45	4.63		1200	6.37	22.93	14.25
	1000	2.06	7.42	4.61		1500	6.31	22.72	14.12
	1200	2.06	7.42	4.61		2000	6.25	22.50	13.98
	1500	2.05	7.38	4.59		3000	6.19	22.28	13.84
	2000	2.05	7.38	4.59		∞	6.08	21.89	13.60
	3000	2.04	7.34	4.56					
	∞	2.03	7.31	4.54	0.8 mm. = 100 km. = 0.1 in. = 197 mi.	271.6	16.22	58.39	36.28
0.4 mm. = 100 km. = 0.1 in. = 395 mi.	135.8	8.12	29.23	18.16		300	12.41	44.68	27.76
	200	5.18	18.65	11.59		400	10.36	37.30	23.18
	300	4.66	16.78	10.43		500	9.68	34.85	21.65
	400	4.48	16.13	10.02		600	9.33	33.59	20.87
	500	4.40	15.84	9.84		700	9.10	32.76	20.36
	600	4.32	15.55	9.66		800	8.95	32.22	20.02
	700	4.27	15.37	9.55		900	8.84	31.82	19.77
	800	4.25	15.30	9.51		1000	8.75	31.50	19.57
	900	4.22	15.19	9.44		1200	8.63	31.07	19.31
	1000	4.20	15.12	9.40		1500	8.52	30.67	19.06
	1200	4.18	15.05	9.35		2000	8.41	30.28	18.82
	1500	4.15	14.94	9.28		3000	8.30	29.88	18.57
	2000	4.13	14.87	9.24		∞	8.11	29.20	18.14
	3000	4.10	14.76	9.17					
	∞	4.06	14.62	9.08					

Latitude 55° (Continued).

ΔB (mm.) / 100 km.	r	$V^{\frac{m}{s}}$	$V^{\frac{km}{hr}}$	$V^{\frac{mi}{hr}}$	ΔB (mm.) / 100 km.	r	$V^{\frac{m}{s}}$	$V^{\frac{km}{hr}}$	$V^{\frac{mi}{hr}}$
1.0 mm. = 100 km. = 0.1 in. = 158 mi.	339.5	20.28	73.01	45.37	2.0 mm. = 100 km. = 0.1 in. = 79 mi.	1200	24.45	88.02	54.69
	400	14.60	52.56	32.66		1500	23.31	83.92	52.15
	500	12.95	46.62	28.97		2000	22.37	80.53	50.04
	600	12.23	44.00	27.34		3000	21.58	77.69	48.27
	700	11.81	42.52	26.42		∞	20.28	73.01	45.37
	800	11.53	41.51	25.79					
	900	11.34	40.82	25.36	2.5 mm. = 100 km. = 0.1 in. = 63 mi.	848.7	50.70	182.52	113.41
	1000	11.19	40.28	25.03		900	40.94	147.38	91.58
	1200	10.98	39.53	24.56		1000	36.50	131.40	81.65
	1500	10.79	38.84	24.13		1200	32.90	118.44	73.60
	2000	10.61	38.20	23.74		1500	30.56	110.02	68.36
	3000	10.44	37.58	23.35		2000	28.83	103.79	64.49
	∞	10.14	36.50	22.68		3000	27.45	98.82	61.40
						∞	25.35	91.26	56.71
1.5 mm. = 100 km. = 0.1 in. = 105 mi.	509.2	30.42	109.51	68.05					
	600	21.90	78.84	48.99	3.0 mm. = 100 km. = 0.1 in. = 53 mi.	1018.5	60.84	219.02	136.09
	700	19.99	71.96	44.71		1200	43.80	157.68	97.98
	800	18.98	68.33	42.46		1500	38.84	139.82	86.88
	900	18.34	66.02	41.02		2000	35.78	128.81	80.04
	1000	17.89	64.40	40.02		3000	33.56	120.82	75.07
	1200	17.30	62.28	38.70		∞	30.42	109.51	68.05
	1500	16.78	60.41	37.54					
	2000	16.33	58.79	36.53	4.0 mm. = 100 km. = 0.1 in. = 39 mi.	1358.0	81.12	292.03	181.45
	3000	15.92	57.31	35.61		1500	62.04	223.34	138.78
	∞	15.21	54.76	34.03		2000	51.78	186.41	115.83
						3000	46.62	167.83	104.28
2.0 mm. = 100 km. = 0.1 in. = 79 mi.	679.0	40.56	146.02	90.73		∞	40.56	146.02	90.73
	700	34.57	124.45	77.33					
	800	29.20	105.12	65.32					
	900	27.12	97.63	60.66					
	1000	25.89	93.20	57.91					

Latitude 60°.

0.2 mm. = 100 km. = 0.1 in. = 789 mi.	60.75	3.82	13.75	8.55	0.4 mm. = 100 km. = 0.1 in. = 395 mi.	121.5	7.60	27.36	17.00
	100	2.36	8.50	5.28		200	4.72	16.99	10.56
	200	2.09	7.52	4.67		300	4.33	15.59	9.69
	300	2.03	7.31	4.54		400	4.18	15.05	9.35
	400	2.00	7.20	4.47		500	4.10	14.76	9.17
	500	1.98	7.13	4.43		600	4.05	14.58	9.06
	600	1.97	7.09	4.41		700	4.02	14.47	8.99
	700	1.96	7.06	4.39		800	3.99	14.36	8.92
	800	1.96	7.06	4.39		900	3.98	14.33	8.90
	900	1.95	7.02	4.36		1000	3.96	14.26	8.86
	1000	1.95	7.02	4.36		1200	3.94	14.18	8.81
	1200	1.94	6.98	4.34		1500	3.92	14.11	8.77
	1500	1.94	6.98	4.34		2000	3.90	14.04	8.72
	2000	1.93	6.95	4.32		3000	3.87	13.93	8.66
	3000	1.93	6.95	4.32		∞	3.80	13.68	8.50
	∞	1.91	6.88	4.28					

Latitude 60° (Continued).

ΔB (mm.) / 100 km.	r	$V \frac{m}{s}$	$V \frac{km}{hr}$	$V \frac{mi}{hr}$	ΔB (mm.) / 100 km.	r	$V \frac{m}{s}$	$V \frac{km}{hr}$	$V \frac{mi}{hr}$
0.6 mm. =	182.25	11.40	41.04	25.50	1.5 mm. =	455.6	28.50	102.60	63.75
100 km.	200	8.87	31.93	19.84	100 km.	500	22.17	79.81	49.59
0.1 in.	300	7.08	25.49	15.84	0.1 in.	600	19.30	69.48	43.17
263 mi.	400	6.62	23.83	14.81	105 mi.	700	18.09	65.12	40.46
	500	6.40	23.04	14.32		800	17.37	62.53	38.85
	600	6.27	22.57	14.02		900	16.90	60.84	37.80
	700	6.19	22.28	13.84		1000	16.56	59.62	37.05
	800	6.13	22.07	13.71		1200	16.10	57.96	36.02
	900	6.08	21.89	13.60		1500	15.69	56.48	35.09
	1000	6.05	21.78	13.53		2000	15.31	55.12	34.25
	1200	5.99	21.56	13.40		3000	14.98	53.93	33.51
	1500	5.94	21.38	13.29		∞	14.25	51.30	31.88
	2000	5.89	21.20	13.17					
	3000	5.84	21.02	13.06	2.0 mm. =	607.5	37.98	136.73	84.96
	∞	5.70	20.52	12.85	100 km.	700	28.14	101.30	62.94
					0.1 in.	800	25.74	92.66	57.58
0.8 mm. =	243.0	15.20	54.72	34.00	79 mi.	900	24.44	87.98	54.67
100 km.	300	10.69	38.48	23.91		1000	23.59	84.92	52.77
0.1 in.	400	9.43	33.95	21.10		1200	22.53	81.11	50.40
197 mi.	500	8.94	32.18	20.00		1500	21.66	77.98	48.45
	600	8.66	31.18	19.37		2000	20.92	75.31	46.80
	700	8.49	30.56	18.99		3000	20.26	72.94	45.32
	800	8.37	30.13	18.72		∞	18.99	68.36	42.48
	900	8.28	29.81	18.52					
	1000	8.21	29.56	18.37	2.5 mm. =	759.4	47.48	170.93	106.21
	1200	8.11	29.20	18.14	100 km.	800	39.14	140.90	87.55
	1500	8.01	28.84	17.92	0.1 in.	900	34.37	123.73	76.88
	2000	7.92	28.51	17.72	63 mi.	1000	32.18	115.85	71.99
	3000	7.84	28.22	17.54		1200	29.86	107.50	66.80
	∞	7.60	27.36	17.00		1500	28.17	101.41	63.01
						2000	26.83	96.59	60.02
1.0 mm. =	303.75	19.00	68.40	42.50		3000	25.72	92.59	57.53
100 km.	400	12.87	46.33	28.79		∞	23.74	85.46	53.10
0.1 in.	500	11.79	42.44	26.37					
158 mi.	600	11.27	40.57	25.21	3.0 mm. =	911.25	56.98	205.13	127.46
	700	10.95	39.42	24.49	100 km.	1000	44.34	159.62	99.18
	800	10.73	38.63	24.00	0.1 in.	1200	38.61	139.00	86.37
	900	10.58	38.09	23.67	53 mi.	1500	35.38	127.37	79.14
	1000	10.46	37.66	23.40		2000	33.12	119.23	74.09
	1200	10.29	37.04	23.02		3000	31.37	112.93	70.17
	1500	10.13	36.47	22.66		∞	28.49	102.56	63.73
	2000	9.99	35.96	22.34					
	3000	9.85	35.46	22.03	4.0 mm. =	1215.0	75.96	273.46	169.92
	∞	9.50	34.20	21.25	100 km.	1500	53.44	192.38	119.54
					0.1 in.	2000	47.18	169.85	105.54
					39 mi.	3000	43.32	155.95	96.90
						∞	37.98	136.73	84.96

Certain Hydro-electric Power Possibilities in the Provinces of Quebec and Ontario, Canada. L. SIMPSON. (*Proceedings of the American Electrochemical Society*, April 28–May 5, 1918.)—Only of late years has it been recognized that more is required of a hydro-electric power development than the existence of a large minimum supply of water under conditions that will permit its use under a reasonably high head, a fairly low cost of development, and a convenient location. It is now recognized that engineering conditions should be such that troubles from ice shall seldom occur and shall at all times be small. Troubles from ice during the last few years became a factor of an importance too considerable to be ignored. Hydro-electric powers which, when only partially developed, were comparatively free from troubles caused by ice, since their completion have been subjected to such serious ice troubles as to change the cost of an apparently low-priced power into one of high price when the loss caused by closing down was added.

In Canada and in the northern section of the United States there are now to be found but few undeveloped hydro-electric power propositions of magnitude that, when properly developed and at reasonable cost, will be comparatively free from ice troubles. Of such power propositions located in Canada and reasonably near the United States, that one situated upon the Ottawa River, 32 miles west of the city of Ottawa, known as the Chats Falls, is probably the best. It is possible at these falls to develop between 110,000 and 120,000 electrical horsepower. The possible head is 50 feet, and troubles from ice can be reduced to a minimum. Another proposition of great magnitude, and one that because of its magnitude may not be so quickly made available, is that which is possible through the construction of a canal from Lake St. Francis to a power-house located on the Lake St. Louis, both these lakes being enlargements of the River St. Lawrence. The possible head is 80 feet, and it will be possible to develop 1,000,000 horsepower.

One of the hydro-electric power developments using the water of Lake St. Francis is particularly interesting because the first direct-connected electric generator was installed in that plant. This generator was built by the General Electric Company, at its Schenectady, N. Y., works, upon an agreement with the then general manager of the Montreal Cotton Company, who proposed the plant, that the builders were to be relieved of all technical and financial responsibility. The success of the installation is now evidenced by the equipment of every modern hydro-electric power-house.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THERMAL EXPANSION OF ALPHA AND OF BETA BRASS BETWEEN 0-600° C[1].

By P. D. Merica and L. W. Schad.

[ABSTRACT.]

In connection with the investigation of the failure of brass by cracking, a comparison has been made of the thermal expansions between ordinary temperature and 600° C. of the two constituents, alpha and beta, of which 60 : 40 brass is composed. The results show that whereas at ordinary temperature the unit expansions of beta brass (55 per cent. copper) and of alpha brass (65 per cent. copper) are very nearly equal — about 18×10^{-6} per degree C.—that of the beta brass becomes about 50 per cent. greater than that of the alpha between 400° and 450° C., just below the beta transformation temperature.

This difference in expansion must result in the existence of differential local or "grain" stresses in a heterogeneous brass containing both alpha and beta when quenched from temperatures higher than from 400 to 500° C. at such a rate of cooling that geometrical adjustment cannot take place between these elements of the mass. The stress distribution in such a quenched brass is very complex; an approximate calculation on certain very arbitrary assumptions would indicate the possibility of the development by quenching of average tensional stresses of 15,000 lbs. 1 sq. in. and more in the beta constituent.

The possible effect of such stresses on the mechanical properties and service behavior of brass and other material is discussed. Experiments showed that these stresses caused in all probability a decrease of the proportional limit over that in the quenched and annealed state. They have failed to show, however, that such quenched brass will "corrosion-crack" in the mercurous nitrate test.

Attention is called to the desirability of studying this feature of heterogeneous alloy structure more fully.

* Communicated by the Director.

[1] Scientific Paper No. 321.

THE PHOTOELECTRIC SENSITIVITY OF BISMUTHINITE AND VARIOUS OTHER SUBSTANCES.[1]

By W. W. Coblentz.

[ABSTRACT.]

THIS paper summarizes the results of an investigation of various substances: (1) for an increase in electrical conductivity caused by the action of light upon them, and (2) for photoelectrical activity when they were charged to a negative potential, in an evacuated chamber, and exposed to light.

Pure gallium and silver sulphide were found to have but small photoelectric activity when charged to a negative potential and exposed to light.

No change was observed in the electrical conductivity of tellurium, boleite, pyrite, silicon, and mixtures of the sulphides of lead and antimony, when exposed to light.

An increase in conductivity was observed in crystals of bismuthinite, cylindrite, molybdenite, selenium, stibnite, boulangerite, jamesonite, and silver sulphide when exposed to light.

Experiments are described in which some of these substances were joined through a battery to the grid circuit of an audion amplifier and a telephone. The light stimulus was interrupted by means of a rotating sectored disk, as used in Bell's selenium photophone. When using a cell or crystal of selenium the fluctuations in light intensity produced a sufficient change in conductivity to cause a musical note in the telephone. Similarly, in some samples of bismuthinite and of molybdenite, a change in conductivity was produced, which caused an audible sound in the telephone receiver. Further experiments are in progress to determine to what extent and for what wave-lengths this is a true photoelectric change (increase) in conductivity, and to what extent this is caused by fluctuations in temperature with a resultant change in resistance within the crystal.

[1] Scientific Paper No. 322.

WAVE LENGTHS IN THE RED AND INFRA-RED SPECTRA OF IRON, COBALT AND NICKEL ARCS.[1]

By W. F. Meggers and C. C. Kiess.

[ABSTRACT.]

It has long been known that the sensitiveness of photographic plates to yellow, red and infra-red light may be increased by staining the plates with certain dyes, but the use of such stained plates in spectrum photography has not been very common. The scarcity of accurate data for wave lengths greater than those of yellow light has led the Bureau of Standards to make extensive application of photographic sensitometry to the study of long wave-length regions in the spectra of the chemical elements. It was thought especially desirable to know to what extent photographic methods combined with powerful dispersive apparatus are applicable to the infra-red spectral regions.

The long-wave regions of the arc spectra of ferrous metals were recorded on plates stained with pinacyanol and with dicyanin. The photographs were made in the first order spectrum of a concave grating with 645 cm. radius of curvature. Exposures of ten minutes' duration sufficed to register the spectrum up to 7000 A; between 7000 A and 9000 A, twenty to thirty minutes' exposure was sufficient, while five to ten hours of exposure recorded many lines whose wave lengths exceed 10,000 A, or one micron. In the arc spectrum of iron, 298 lines were measured between the wave-length limits 6750 A and 10,689 A; 606 lines were measured between 5503 A and 11,623 A in the arc spectrum of cobalt, and 290 lines between 5504 A and 10,843 A in the arc spectrum of nickel. The large number of lines photographed in the infra-red spectra of these arcs shows the importance of using and developing photographic methods as far as possible. The photographic has great advantages over the radiometric method in being able to record fainter lines and resolve complex or close lines, in addition to allowing greater possible accuracy in the wave-length measurements. In the spectral region in which the above mentioned photographs overlap radiometric observations, from 5 to 10 times as many lines

[1] Scientific Paper No. 324.

were recorded as were observed by means of the radiometer. However, for waves longer than about 10,000 A the sensitiveness of the radiometer so enormously exceeds that of photographic plates at the present time that it is necessary to rely on the radiometer for practically all spectroscopic data. Extensive and careful investigations in the region to which both methods apply should assist in removing some of the difficulties and uncertainties in studying the longer waves. For this purpose the use of dicyanin is strongly recommended since it makes an invisible long wave interval as large as the entire visible spectrum accessible to photography.

SPECTRO-RADIOMETRIC INVESTIGATION OF THE TRANSMISSION OF VARIOUS SUBSTANCES.[1]

By W. W. Coblentz, W. B. Emerson and M. B. Long.

[ABSTRACT.]

THIS paper gives the spectral transmission of various substances, especially colored fluorite and colored glasses.

In some scientific investigations it is desired to expose large areas to radiant energy stimuli of a fairly high spectral purity. Some of the substances described in this paper provide a simple means of obtaining narrow spectral bands of energy of high intensity, and large area without employing a spectroscope.

By properly combining these substances one can obtain a screen having a narrow band of high transmission at 0.38 μ, 0.5 μ, 0.55 μ, 0.7 μ, 0.8 μ, 1 μ, and 2.2 μ.

The data on glasses are also useful in connection with the question of protecting the eyes from injurious radiations.

[1] Scientific Paper No. 325.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE IODIDE TITRATION OF SILVER NITRATE WITH PALLADIOUS NITRATE AS THE INDICATOR.[1]

By Louis Schneider.

[ABSTRACT.]

THIS new method is especially adapted for the determination of very small amounts of silver with accuracy, and overcomes the effect of those metals that usually interfere with the Volhard method. The method consists of the titration of silver nitrate with potassium iodide in the presence of a very small amount of palladious nitrate. The silver nitrate is precipitated by the potassium iodide and the slightest excess of potassium iodide is converted by the palladious nitrate to palladious iodide which is strongly colored.

In applying the palladium indicator it was found necessary to employ a protective colloid, such as gum arabic to prevent the occlusion of silver nitrate or potassium iodide in tenth normal titrations, and, in very dilute solutions, in order to obtain a precise colorimetric comparison in determining the end point.

The errors of the method are discussed and may be avoided by adherence to the recommended method of procedure. An accuracy of 0.1 per cent. is easily obtained.

A NEW METHOD OF OBTAINING DYE TONED IMAGES BY THE USE OF COPPER FERROCYANIDE AS A MORDANT.[2]

By J. I. Crabtree.

[ABSTRACT.]

As a result of a search for mordants of basic dyes other than silver iodide, it was found that by replacing more or less

* Communicated by the Director.

[1] Communication No. 59 from the Research Laboratory of the Eastman Kodak Company, published in *Journal American Chemical Society*, April, 1918, p. 583.

[2] Communication No. 72 from the Research Laboratory of the Eastman Kodak Company, published in *Phot. J. Am.*, 1918, p. 338; *Mot. Pic. News*, Aug. 17, 1918, p. 1104, and Aug. 24, p. 1278.

of a silver image by copper ferrocyanide, by toning in the usual copper-toning bath, washing, and then immersing in an acid solution of a basic dye, dye-toned images were obtained.

The usual copper toning bath consists of a solution of copper ferricyanide dissolved in a suitable solvent, such as a solution of an alkaline salt, of citric, tartaric, or oxalic acid, together with other salts. On immersing the silver image in such a bath the silver reacts with the copper ferricyanide and is converted to silver ferrocyanide, while copper ferrocyanide is formed simultaneously in combination with the image.

On immersing this image in a solution of a suitable basic dye a composite image is obtained consisting of a mixture of silver, silver ferrocyanide, copper ferrocyanide and the dye, so that the color of the toned image produced is of a color intermediate between that of the dye and the copper compound, depending on the relative proportion of each. The amount of copper salt necessary to mordant the dye is usually so small that the resultant tone differs but slightly from that of the dye itself. After toning in the copper-toning bath for a few minutes the positive is washed for ten minutes and immersed in the dye solution, which contains a little acid. After dyeing only a mere rinse of water is necessary before drying.

If the highlights are stained, the positive should be washed for five or ten minutes or until clear. Stained highlights are caused either by insufficient washing after toning, too strong a dye bath, or an incorrect amount of acid in the dye bath.

Satisfactory tones may be secured with the following dyes: Tannin Heliotrope, Thioflavine, Victoria Green, Methyl Green, Methylene Blue, Chrysoidine, Methyl Violet.

Intermediate dye tones may be obtained by mixing two or more dyes, and pale tones by giving a short bath in the copper solution and fully dyeing, or by toning for a longer time and giving a short immersion in the dye bath.

A feature of the toned images produced in the above manner is their transparency. The transparency depends on the composition of the copper toning bath and on the fineness of grain of the silver image to be toned. For toning lantern slides the best results are obtained on the "slow" variety of plates, which are usually of fine grain.

THE FRANKLIN INSTITUTE.

MEMBERS OF THE FRANKLIN INSTITUTE WHO ARE IN THE ACTIVE MILITARY OR NAVAL SERVICE OF THE UNITED STATES GOVERNMENT.

Name and rank	Branch of service	Location
Allen, Henry B., Captain	Ordnance Dept., N. A.	France
Anderson, Geo. L., Colonel	Board of Ordnance & Fortification	Washington
Atherholt, Gordon Meade	Aeronautical Mechanical Engineer, Signal Corps	Washington
Atterbury, W. W., Brig. Gen.	Director-General of Railways	France
Bacon, Raymond Foss, Lt. Col.	Head of Chemical Service Section, U.S.N.A.	France
Barnhart, G. Edw.	Aeronautical Mechanical Engineer, Signal Corps	Fairfield, Ohio
Barr, John H., Major	Ordnance Reserve Corps	Washington
Barrett, C. D., Major	9th Engineers	
Bartow, Edward, Major	U.S.N.A. Sanitary Corps	France
Billings, A. W. K.	Chief Engineer, U. S Naval Forces (Aviation)	London
Booz, Horace Corey, Colonel	Railroad Transportation Corps, U.S.N.A.	France
Bostwick, John Vaughan, Capt.	O.R.C., 315th Infantry	
Breed, George, Lieutenant	Fleet Naval Reserve, U.S.N. R.F.	New York
Bunting, C. M., Colonel	E.O.R.C., U.S.A.	France
Cadwalader, Governeur, Major	Ordnance Dept., U.S.R.	
Caldwell, E. W.	Medical Officers' Reserve Corps	
Capps, W. L., Rear Admiral	Chief Constructor, U.S.N., Bureau of Construction and Repair	Washington
Carty, John J., Colonel	Signal Corps, U.S.A.	
Cathcart, Wm. L., Lieut. Com.	U. S. N. R. F.	Washington
Chance, Edwin M., Capt.	Ordnance Dept., U.S.R.	Washington
Clark, Beauvais, Sergeant	108th Field Artillery	Camp Hancock
Clark, E. L., 1st Lieut.	Signal Corps, 401st Telegraph Battalion	Camp Devens
Clark, Theobald F., Capt.	Field Artillery	
Clark, Walton, Jr., Capt.	Field Artillery	
Coates, Jesse, Major	American Expeditionary Force	France
Cope, Thomas D., 1st Lieut.	Air Service, U. S. A.	Langley Field
Cornelius, John C., 1st Lieut.	Coast Artillery, U.S.N.A., 13th Company	Sandy Hook
Cottrell, Jas. W., Sergeant	Instructor Ordnance Motor Instruction School	Metuchen, N. J.
Cowan, Henry B., Sergeant, 1st Class	Co. D., First Telegraph Battalion, Signal Reserve Corps	France
Crampton, George S., Major	Director of Field Hospitals, 28th Div.	Camp Hancock
Cushman, A. S., Lieut. Col.	Ordnance Dept., U.S.N.A.	Frankford Arsenal

Name and rank	Branch of service	Location
Detwiler, Jas. G., 1st Lieut.	Infantry, U.S.R.	Fort Logan H. Roots
Eckert, S. B., Lieut.	Commander 9th Aero Squadron	France
Edwards, John R., Rear Admiral	Brown University	Providence, R.I.
Elliot, A. H.	Engineers Reserve Corps	Philadelphia
Elliott, Henry M., 1st Lieut.	Ordnance Dept., U.S.R.	Western Cartridge Co.
Emerson, Geo. H., Colonel	In charge of Russian Railway Service Corps	Japan
Felton, Samuel M.	U. S. Director-General of Railways in connection with Expeditionary Force	Chicago
Ferguson, Walter B., Sergeant	21st Co., 154th Depot Brigade	Camp Meade
Fraser, Persifor, Ensign	U.S.N.R.F.	League Island
Gardner, H. A., Senior Lieut.	Naval Flying Corps	Washington
Gfrörer, A. H., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Gibbons, Joseph E., Private	Co. D., 103rd Engineers	Camp Hancock
Gilbreth, Frank B., Major	Engineers O. R. C.	Washington
Gillmor, R. E., Senior Lieut.	U. S. Navy	New York
Glendinning, Robt. E., Major	Aviation Section, Signal Corps	Overseas
Gomberg, M., Major	Ordnance Reserve Corps	Washington
Goodwin, Harold, Jr., Lieut.	Naval Reserve Force	Philadelphia
Gribbel, W. G., Captain	Co. A., 30th Engineers, U.S.R. (Gas and Flame)	France
Griest, Thos. S., 1st Lieut.	1st Telegraph Battalion, Signal Corps, U.S.A.	France
Hall, R. T., Rear Admiral	U. S. Navy, Inspector of Machinery	Cramps' Shipyard
Hammer, William J., Major	Inventions Section, War Plans Division, General Staff, War College	Washington
Hodges, Austin L., Capt.	Ordnance Dept., U.S.R., Experimental Officer on Artillery Ammunition	Frankford Arsenal
Howson, Richard, 2nd Lieut.	Field Artillery	Camp Zachary Taylor
Ives, H. E., Captain	Signal Corps, U.S.A.	Washington
Jackson, John Price, Major		France
Jones, Jonathan, Captain	E.O.R.C., 23rd Engineers	Camp Laurel
Junkersfeld, P. Major	E. O. R. C.	Washington
Karrer, Enoch, Private	437th Engineers	Washington
Kennedy, M. C., Colonel	Deputy Director General of Transportation	France
Kent, S. Leonard, Jr., 2nd Lieut.	5th Engineers	Camp Lee
Kingsbury, E. F., 1st Lieut.	Aviation Section, S.O.R.C., Dept. of Science and Research	Washington
LeBoutillier, H. W., Private	Unit No. 10, Pennsylvania Hospital	France
Lenher, Victor, Major	Chemical Warfare Service, N.A.	Washington
Lichtenberg, Chester, 1st Lieut.	Engineer Reserve Corps, U.S.A.	Washington
Lippincott, Joseph Wharton, Yeoman, 1st class	U. S. Naval Reserves	Washington
Littleton, Wm. Richards	Assistant Paymaster, U. S. N.	Philadelphia
Longstreth, Chas., Lt. Commander	U.S.N.R.F.	Philadelphia
Lucke, Charles E., Lt. Commander	U.S. Navy Gas Engine School	New York City, New York
McCoy, John F.	Aviation Section, Signal Corps	Princeton

Name and rank	Branch of service	Location
MacLean, Malcolm R., Major	Infantry R. C.	Camp Meade
McMeekin, C. W., Major	Army War College	Washington
Martin, Thos. S., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Masters, Frank M., Major	Ordnance Dept., U.S.R.	Washington
Maxfield, H. H., Lieut. Col.	19th Railway Engineers, U.S.N.A.	
Mershon, Ralph D., Major	E.O.R.C., U.S.A.	New York
Miller, Fred. J., Major	Ordnance Reserve Corps	Centre Bridge, Penna.
Owens, R. B., Major	Chief Signal Officer, Base Section No. 3, A.E.F.	London
Parrish, T. R., Captain	Signal Corps	Washington
Reber, Samuel, Colonel	Signal Corps, U.S.A.	New York
Richardson, Chas. E., 1st Lieut.	30th Engineers, U.S.R. (Gas and Flame)	France
Sessler, Grover C.	Assistant Civil Engineer, U. S. N. R. F.	Philadelphia
Spackman, Henry S., Major	Engineer Officers' Reserve Corps	France
Spruance, W. C., Jr., Lt. Col.	Ordnance Dept., National Army	Chevy Chase. Md.
Squier, Geo. O., Major General	Chief Signal Officer, U.S.A.	
Stanford, H. R., Civil Engineer	U. S. Navy	Boston
Thomas, Geo. C., Jr., Captain	Aero Service Squadron 96, Aviation Section, Signal Corps	France
Tilghman, B. C., Captain	A.D.C., 28th Div. Headquarters, U.S.A.	
Vogleson, J. A., Major	Sanitary Corps	Camp Jas. E. Johnston
Wagner, Fred. H., Major	Ordnance Reserve Corps, Nitrate Division	Washington
Wagner, Fred. H., Jr., Sergeant	Co. E., 304th Engineers	Camp Meade
Wells, G. A., Captain	Ordnance Reserve Corps	Peoria, Ill.
Wetherill, W. C., Ensign	U. S. Navy	
Widdicombe, R. A., Major	C.Q.M., Chemical Plant No. 4	Saltville, Va.
Wood, Edw. R., Jr., Captain	18th Field Artillery, U.S.N.A.	El Paso, Texas
Worrell, Howard Sellers	3rd Officers' Training Camp	Fortress Monroe
Wyckoff, A. B., Lieut.	U. S. Navy	Ontario, Cal.
Yale, A. W. Major	Medical Reserve Corps, Gas Division	Camp Kearney
Yorke, George M., Major	Signal Corps, U.S.R.	New York

MEMBERS DOING CIVILIAN WORK FOR THE UNITED STATES GOVERNMENT

Name	Appointment	Location
Akeley, Carl E.	Consulting Expert of Mechanical Devices, War Department	Washington
Anderson, Robt. J.	Aeronautical Mechanical Engineer on Metallography, Bureau of Aircraft Production	Pittsburgh, Pa.
Balls, William H.	Ships Draughtsman	Phila. Navy Yard
Bancroft, Joseph	Secretary, Local Board No. 1	Wilmington
Baskerville, Charles	Working with Bureau of Mines, Ordnance Dept. (Gas Warfare, Shells, etc.)	New York
Bodine, Samuel T.	Vice-Chairman, District Exemption Board, No. 1, Eastern Judicial District of Penna.	Philadelphia

Name	Appointment	Location
Brown, Lucius P.	Federal Milk Commission	New York
Burnham, George, Jr.	Dept. of Civilian Service and Relief, Public Safety Committee of Pennsylvania	Philadelphia
Charles, Bernard S.	Ordnance Inspector, U. S. Navy	Allentown, Pa.
Comey, Arthur M.	Chairman, Sub-Committee on Explosives, Chemistry Committee, National Research Council	Chester, Pa.
Condict, G. Herbert	Naval Consulting Board, Member Committee of Examiners	Plainfield, N. J.
Cooke, Morris L.	Chairman, Storage Committee of Munitions Board; Member on Staff, Emergency Fleet Corporation	Washington
Day, Charles	Member of Army War Council	Washington
Delano, Frederic A.	Member of Federal Reserve Board	Washington
Dunn, Gano	Chairman, Engineering Committee, National Research Council	New York
Garrison, Frank Lynwood	Chairman, U. S. Manganese Commission	Philadelphia
Henderson, George R.	State Advisory Engineer, Federal Fuel Administration for Pennsylvania	Philadelphia
Hornor H. A.	Electrical expert for Industrial Training, Emergency Fleet Corporation	Philadelphia
Hoskins, Wm.	Consulting Chemist, Advisory Committee, Bureau of Mines; Associate Member, Naval Consulting Board	Chicago
Hyde, Edward P.	National Research Council, Sub-Committee on Monocular vs. Binocular Field-Glasses (Chairman)	Cleveland
Insull, Samuel	Chairman, Illinois State Council of Defense	Chicago
Keller, Harry F.	Assistant Director of Allied Bodies, Department of Public Safety of Penna.	Philadelphia
Kennelly, A. E.	Conducting special course in radio-engineering for the U. S. Signal Corps, in conjunction with Prof. E. C. Chaffee	Harvard Univ.
Lloyd, E. W.	Asst. Secretary, Illinois State Council of Defense	Chicago
Merrick, J. Hartley	Director, Bureau of Camp Service, Penna. Div., American Red Cross	Philadelphia
Milne, David	Treasurer, American Red Cross, General Hospital No. 1	Philadelphia
Morris, Effingham B.	Treasurer, Committee of Public Safety, State of Pennsylvania	Philadelphia
Nichols, Carroll B.	Fuel Administration	Washington
Nichols, Wm. H.	Committee on Chemicals, Advisory Council of National Defense, Consulting Chemist, Bureau of Mines	New York
Penrose, R. A. F., Jr.	Member of Geology Committee of the National Research Council	Philadelphia
Picolet, L. E.	Civilian Personnel, Trench Warfare Section, Ordnance Office	Washington
Rapp, Isaiah M.	Special Investigator of Weights and Measures for the U .S. Food Administration	Norman, Oklahoma
Rautenstrauch, Walter	Committee of the National Research Council	New York

Name	Appointment	Location
Richards, Joseph W.	Member of Naval Consulting Board	So. Bethlehem, Penna.
Robins, Thomas	Member and Secretary of the Naval Consulting Board	New York
Sauveur, Albert	Director of Research, Division of Metallurgy, Technical Air Service, A.E.F.	France
Sperry, Elmer A.	Member of Naval Consulting Board	Brooklyn, N.Y.
Sprague, Frank J.	Member of Naval Consulting Board, Chairman, Committee on Electricity and Shipbuilding	
Steinmetz, Joseph A.	Member National Research Council, Engineering Division	Washington
Stern, Max J.	Supervising Surgeon, Merchant Shipbuilding Corporation	Philadelphia
Stradling, George F.	Recruiting for Aviation Section, S.O.R.C.	Philadelphia
Swenson, Magnus	Federal Food Administrator for Wisconsin; Chairman, State Council for Defense	Madison, Wis.
Taggart, Walter T.	Consulting Chemist, Nitrate Division, Ordnance Department	Philadelphia
Talbot, Henry P.	Member of Advisory Board, Bureau of Mines (Gas Defense)	Cambridge, Mass.
Thomson, Elihu	National Research Council in coöperation with Council of National Defense	Swampscott, Mass.
Wadleigh, Francis R.	Emergency Fleet Corporation	Philadelphia
Warwick, J. F.	Bethlehem Loading Co.	Mays Landing, N J.
Wharton, Henry	Y. M. C. A.	France

Please send additional information and corrections to the Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, September 4, 1918.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 4, 1918.

DR. H. JERMAIN CREIGHTON *in the Chair.*

The following report was presented for first reading:

No. 2722.—Calorizing Process.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 11, 1918.)

RESIDENT.

MR. ALFRED CROOK, Vice President and General Manager, Philadelphia Roll and Machine Company, 25th Street and Washington Avenue, Philadelphia, Pennsylvania.

MR. CHARLES S. HOLLANDER, Chemist and Chemical Engineer, Rohm and Haas Company, Bristol, Pennsylvania.

NON-RESIDENT.

MR. WILLIAM E. BULLOCK, Mechanical Engineer, 26 Maxweber Avenue, Jamaica, New York.

MR. FRANCIS G. PEASE, Astronomer and Engineer, Solar Observatory, Pasadena, California, and for mail, 1023 16th Street, Washington, D. C.

MR. JAMES R. WATKINS, Civil Engineer, Forest Products Laboratory, and for mail, 1315 Spring Street, Madison, Wisconsin.

ASSOCIATE.

MR. WILLIAM HOPPIN, Internal Combustion Engineer, Y.M.C.A., Detroit, Michigan.

NECROLOGY.

Mr. G. W. Dickie, 24 California Street, San Francisco, California.
Mr. Joseph Hartshorne, 524 High Street, Pottstown, Pennsylvania.

BOOK NOTICES.

JOURNAL OF THE AMERICAN CERAMIC SOCIETY. This is the initial number of a journal, to appear monthly, devoted to the "Arts and Sciences Related to the Silicate Industries." It is of usual octavo size, the present issue containing 72 pages of text with numerous illustrations and 10 pages of advertisements. One of the most interesting papers is by A. V. Bleininger, of Pittsburgh, on the manufacture of optical glass. From this we learn that a very important feature of the work is the production of suitable pots and this problem seems to have been practically solved. One of the speakers in discussion said: "We now have an optical-glass industry in this country well started, and we are able to take care of our military requirements with a very considerable degree of satisfaction."

The new journal will be welcome in the field of American scientific literature.

HENRY LEFFMANN.

AGRICULTURAL BACTERIOLOGY. By H. W. Conn, Ph.D. Third edition, revised by Harold Joel Conn. Philadelphia, P. Blakiston's Son & Company, 1918. x + 357 pages, illustrations, 12mo. Price $2.00 net.

Eight years have elapsed since the last revision of this treatise. In the present edition, special attention has been paid to those divisions of agricultural bacteriology in which the greatest advance has been made during that period.

The introductory chapters describe the general nature of microörganisms and their activities. The section on soil and water is devoted to such sub-

jects as the carbon and nitrogen cycles, manure, sewage and its treatment, relation of bacteria to the ash constituents of plants, soil fertility, drinking water, and stream pollution. Among the subjects discussed in the section on milk are bacterial changes in milk, milk-born diseases, control of milk supply, and the manufacture of butter, oleomargarine, and hard and soft cheeses. The bacteriology of alcohol, vinegar, sauer-kraut, tobacco, silage, and flax are described in one chapter, while the preservation of food products by drying, cold, preservatives, and canning receives attention in another chapter.

The concluding chapters give an outline of infection, immunity, and resistance, and a description of diseases of plants and animals produced by bacteria, fungi, and other lower parasites.

The appendix of 20 pages is an elementary laboratory manual, describing laboratory apparatus and reagents and the preparation of media, and giving directions for experiments, such as isolation of bacteria in pure culture, determination of bacterial count, study of morphology, motility and biochemical activity, and disinfection.

JOSEPH S. HEPBURN.

PUBLICATIONS RECEIVED.

TNT Trinitrotoluenes and Mono—and Dinitrotoluenes. Their Manufacture and Properties, by G. Carlton Smith, B.S., 133 pages, 12mo. New York, D. Van Nostrand Co., 1918. Price, $2.00.

Methods of Measuring Temperature, by Ezer Griffiths, D.Sc., with an introduction by Principal E. H. Griffiths, F.R.S. 176 pages, illustrations, 8vo. London, Charles Griffin & Sons, Ltd., 1918. American representatives, J. B. Lippincott Company.

Chemical Combination Among Metals, by Dr. Michele Giua and Dr. Clara Giua—Lollini. Awarded the prize of the Cagnola foundation by the Royal Lombardy Institute of Science and Literature. Translated by Gilbert Wooding Robinson. 341 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son & Co., 1918. Price, $4.50 net.

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United States Tariff Commission: Tariff Information Series No. 5. The glass industry as affected by the war. 147 pages, 8vo. Washington, Government Printing Office, 1918.

The Deposition of Silver Films on Glass. A. SILVERMAN and R. M. HOWE. (*The Journal of Industrial and Engineering Chemistry*, vol. 9, No. 11, p. 1032, November, 1917.)—The purpose of this investigation is threefold: to produce the best mirrors possible, to secure the highest possible percentage deposition, and, if possible, to obtain these results at room temperatures.

In hot processes cane-sugar is the most satisfactory reducing agent. Other sugars give good results, but no better than cane-sugar. The tartrates are not as satisfactory as the sugars. A rapid cold process was developed. It requires a batch of the following proportions used as indicated: 20 c.c. of 0.2 molar silver nitrate solution are mixed with 0.5 c.c. of 80 per cent. methyl alcohol; to this 0.5 c.c. of 40 per cent. formaldehyde is added and the whole mixed thoroughly.

A slow cold process was developed which is based upon the following principles: (1) Low concentration of the reducing agent (formaldehyde) gives the best results. This helps lengthen the time of reaction. (2) Low concentration of silver nitrate gives high deposition percentages. (3) Sugar added to the solution in sufficient amounts controls the action of the formaldehyde in such a way as to produce even mirrors. It also lengthens the time of action. (4) Alcohol added to the solution results in a high deposition efficiency. By grouping these principles the following batch results: 16.5 c.c. of 0.037 molar silver solution; 1.0 c.c. of 1.000 molar cane-sugar solution; 0.5 c.c. of 80 per cent. methyl alcohol; 2.0 c.c. of 0.8 per cent. formaldehyde solution. Total, 20 c.c. After 40 minutes, over 20 per cent. of the total silver deposits as mirror in each case, and if left longer a heavier mirror results. The cost of materials is not over one cent per square foot, and eleven cents per square metre of surface silvered. The mirror is very firmly attached to the glass for two reasons: (1) The temperature of the glass and solution is the same: as a result, deposition is more uniform than that which occurs at higher, more difficultly controllable temperatures. (2) Since deposition takes place at room temperature, differences in coefficient of expansion do not cause the newly formed mirror to be loosened from the glass, as may be the case where hot processes are employed.

CURRENT TOPICS.

American Artillery. ANON. (Circular from the Committee on Public Information, April 20, 1918.)—To-day the two dominating factors in the struggle for world supremacy are still the bayonet and heavy artillery. Without the support of either success is impossible. Big guns play a major part in deciding battles, now as in the day of Napoleon. For this reason it is interesting to know something about the different kinds of big gun being made for our army in France. Artillery may be divided into two classes—mobile artillery, which includes all guns used in the field, and seacoast artillery, which is used in fortifications on fixed mounts. It is the mobile artillery which we are vitally interested in at the present time for offensive work on the French front. This mobile artillery is divided into three distinct types—guns, howitzers, and mortars.

The first of these are long-range rifles distinguished by high muzzle velocity and long barrels of from 30 to 50 calibres; that is to say, the length of barrel ranges from thirty to fifty times the diameter of the bore, giving a range of from 6000 to 30,000 yards with a low angle of fire. These guns are classified as wheel mounts, anti-aircraft (truck mounts), emplacement mounts, and railway mounts. The wheel mounts are subdivided as pack artillery (mountain guns transported on pack mules); field guns, drawn by horse teams and attached to rumbles; motorized field guns, drawn by big ammunition trucks; tractor-drawn guns of large calibre; and the so-called horse artillery, drawn by horses, with all cannoneers mounted, for fast field work in support of cavalry.

The wheel-mount guns include the famous French 75 (3-inch) and 4.7-inch guns, which have created such havoc among their German opponents and which have been responsible for breaking down the greatest military offensives of the Germans in the past three years. The 4.7 are of greater range and calibre, but of practically the same type as the 75 mm. Next in order, according to size, come the 5-inch and the 6-inch seacoast guns, such as our allies have withdrawn from the fortifications and mounted on improvised wheel mounts, for use as mobile artillery.

The second class are the anti-aircraft guns, for which purpose 75's and 4.7's are provided, mounted on a carriage which will allow an elevation of about 85 degrees and a traverse of 360 degrees, set up on a motor truck. Emplacement mounts are large-calibre guns that are partially mobile. They are taken apart and moved around in sections in tractors as needed, and set up in concrete emplacements. They are, more strictly speaking, siege guns. The railway-mount guns are converted seacoast and naval long-range rifles of

from 8 to 14 inches calibre. They have a mount consisting of a specially designed carriage on a railway car and they are operated, due to their extreme range and accuracy, far back from the front lines over the heads of our own troops. This covers the first class of mobile artillery—the long-range rifles. Next in order come the howitzers.

The howitzer is distinguished from the rifle by a low muzzle velocity ranging from 1200 to 1900 feet per second, and a short barrel, approximately eighteen times the calibre of the gun, developing a range at high angle fire of from 10,000 to 23,000 yards. The commonest sizes of howitzer in use are the 155-mm., the 8-inch, the 240-mm., and, of course, the famous 16-inch howitzer which we heard so much about in the early days of the war, when the Germans, who first used them, created such dreadful havoc, destroying with them the fortifications of Liège. The smaller sizes, such as the 155-mm. and the 8-inch, are used principally for field work, but also for the bombardment of permanent fortifications when necessary.

Howitzers have the advantage of being cheaper to make than guns, and use cheaper ammunition. Also, the life of the gun is longer. Indicative of this, the life of a howitzer of the same calibre as a gun would be about two-thirds longer. But they are not as accurate and have not as long range as the guns and consequently are not adapted for all work. The life of the guns ranges from 8000 rounds for the small field type down to 600 or 700 for the converted seacoast guns. These figures denote only the actual accuracy life. It is probable that the guns will be fired up to 50 per cent. above these figures before retiring them. By relining the barrels the life of the gun is practically renewed.

Mortars are distinguished by even lower muzzle velocity, from about 480 to 2000 feet per second, and by a length of barrel of about 10 calibres, with a range of from 2500 to 15,000 yards. This extreme range is obtained by a very high angle of elevation. The common French type is the 240-mm. mounted on a railway carriage.

This practically covers the principal guns which are used by our allies to-day and with which our troops will be equipped in France. The 3-inch and 4.7-inch guns, U. S. Army Model of 1906, are practically the same in general principle as the French 75 and 155, which are of the corresponding calibre. But it must be remembered that our allies have had three years' actual experience with which to perfect many of the minute details which are so important in the effectiveness of a field gun and which are only discovered under actual field conditions of long duration. This has led to great improvements over the guns originally in use.

As indicative of the tremendous amount of material that one regiment of 75's comprises, it is interesting to know that there are approximately 300 vehicles, exclusive of the actual fighting material, to each regiment. These vehicles are trailers, tractors, and trucks, and artillery repair trucks and supply trucks. In the actual fighting

material there are 24 guns, 36 caissons, 60 limbers, and the reel carts for the field telephone, making a grand total of approximately 430 vehicles to a regiment.

The estimated cost of the motorization of the artillery alone of the United States Army is $500,000,000, of which approximately $210,000,000 had been expended on the 1st of February. Ammunition trucks and vehicles are being completed faster than they can be shipped. Up to the present time the sum of $776,000,000 has been expended by the Procurement Division of the Ordnance Department in the purchase of projectiles. With this sum about 65,000,000 projectiles have been purchased. These include shrapnel, high-explosive type, and gas and anti-aircraft shells for howitzers and guns, weighing from 12 pounds to 1600 or 1700, and costing from about $10 to $125 each, exclusive of the cost of explosives or of loading the complete round.

The Electrolytic Behavior of Manganese in Sulphate Solutions. G. D. VAN ARSDALE and C. G. MAIER. (*Proceedings of the American Electrochemical Society*, April 28–May 5, 1918.)—In prewar times the manganese ore needed for the steel and other large-scale industries in this country was supplied by importation largely from Russia. Since the outbreak of the war importation from this source has ceased. There are large deposits of metallurgical manganese ore in Brazil, and fairly extensive, though largely undeveloped, deposits in this country. The two alternative solutions of the problem, therefore, have been either the diversion of sufficient shipping for importing manganese ore from Brazil or the development and utilization of our domestic deposits. Since shipping has been and is so urgently needed for other purposes, the second alternative would appear desirable, if possible. Moreover, since it is at least possible that the importation of high-grade ore will be seriously hindered for even a considerable period after the war, the use of domestic ore is not entirely one of immediate or temporary expediency.

While deposits of manganese oxide and carbonate ore are fairly extensive in the United States, many of them are of too low grade to be of much direct use. Mechanical concentration of these ores has been unsatisfactory, particularly from the point of view of efficiency of recovery. Smelting of low-grade ores will always be attended with serious difficulties and large slag losses. It seems, consequently, that some chemical method of concentrating ores might be the best solution of the problem, and, if well established, might even persist under post-war conditions.

Some preliminary results of an attempt to solve the problem along electrochemical lines are given in this paper. It was early realized that the most practical and convenient avenue for separating manganese from its ores was solution as manganese sulphate. Such a solution is also the form most amenable to elec-

trolytic treatment. Current efficiencies, voltages, and conditions affecting the nature of the deposits formed by electrolyzing manganese sulphate have been studied. The factors affecting the deposition of elementary manganese at the cathode are discussed. The efficient plating-out of manganese dioxide at the anode is shown to be possible under certain circumstances, and the chemical conditions influencing the possible utilization of this reaction are pointed out.

Cast Iron at High Temperatures. ANON. (*Power*, vol. 48, No. 4, p. 120, July 23, 1918.)—Comparatively little information is available on the strength of iron and steel at high temperatures. Most of the tests published are of European origin and are either buried in voluminous reports or in foreign-language literature. These tests have recently been sought and collected by the Vulcan Soot Cleaner Company. Permanently installed soot cleaners must often be placed in temperatures that are comparatively high, and it is important to have data on the strength of the materials employed under these conditions.

As the temperature is increased, steel, wrought iron and cast iron grow stronger up to a certain point. Thus the maximum strength of wrought iron occurs at 450° Fahr. and the corresponding temperature for steel is 525° Fahr. With further increase in temperature both the ultimate and elastic strength decrease rapidly. At 1000° Fahr. the strength of wrought iron is seriously diminished, and steel has no elastic strength. If soot-cleaner elements are made of steel alone, and if they are heated to a temperature of 1000° Fahr. they are liable to sag from their own weight and become inoperative in a short time. The diminution of the strength of cast iron, on the other hand, is much less within the same temperature-range, the strength of soft cast iron is practically constant between 100 and 1000° Fahr. Cast iron of almost any good composition will protect soot-cleaner elements sufficiently, but for the sake of safety a special tested uniform grade is used. Besides being little affected by the temperature, the cast iron sheath, making the element somewhat larger, increases the rate of radiation and thus insures a lower temperature.

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